JE 2 '58

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

GEOLOGY OF THE
HUNTINGTON LAKE AREA
FRESNO COUNTY, CALIFORNIA

SPECIAL REPORT 46
1956

UNIVERSITY
OCT 2 1956
LIBRARY

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

SPECIAL REPORTS ISSUED BY THE DIVISION OF MINES

1-A. Sierra Blanca limestone in Santa Barbara County, California, by George W. Walker. 1950. 5 pp., 1 pl. Price 25¢

1-B. The Calera limestone, San Mateo and Santa Clara Counties, California, by George W. Walker. 1950. 8 pp., 1 pl., 6 figs. Price 25¢.

2. Geology of part of the Delta-Mendota Canal near Tracy, California, by Parry Reiche. 1950. 12 pp., 5 figs. Price 25¢.

3. Commercial "black granite" of Diego County, California, by Richard A. Hoppin and L. A. Norman, Jr. 1950. 19 pp., 18 figs. Price 25¢.

4. Geology of the San Dieguito pyrophyllite area, San Diego County, California, by Richard H. Jahns and John F. Lance. 1950. 32 pp., 2 pls., 21 figs. Price 50¢.

5. Geology of the Jurupa Mountains, San Bernardino and Riverside Counties, California, by Edward M. MacKevett. 1951. 14 pp., 1 pl., 14 figs. Price 25¢.

6. Geology of Bitterwater Creek area, Kern County, California, by Henry H. Heikkila and George M. MacLeod. 1951. 21 pp., 2 pls., 15 figs. Price 35¢.

7-A. Gem- and lithium-bearing pegmatites of the Pala district, San Diego County, California, by Richard H. Jahns and Lauren A. Wright. 1951. 72 pp., 13 pls., 35 figs. Price $2.50.

7-B. Economic geology of the Rincon pegmatites, San Diego County, California, by John B. Hanley. 1951. 24 pp., 1 pl., 5 figs. Price 35¢.

8. Talc deposits of steatite grade, Inyo County, California, by Ben M. Page. 1951. 35 pp., 11 pls., 25 figs. Price 85¢.

9. Type Moreno formation and overlying Eocene strata on the west side of the San Joaquin Valley, Fresno and Merced Counties, California, by Max B. Payne. 1951. 29 pp., 5 pls., 11 figs. Price 60¢.

10-A. Nephrite jade and associated rocks of the Cape San Martin region, Monterey County, California, by Richard A. Crippen, Jr., 2d printing. 1951. 14 pp., 14 figs. Price 25¢.

10-B. Nephrite in Marin County, California, by Charles W. Chesterman. 1951. 11 pp., 16 figs. Price 25¢.

10-C. Jadeite of San Benito County, California, by H. S. Yoder and C. W. Chesterman. 1951. 8 pp., 6 figs. Price 25¢.

11. Guide to the geology of Pfeiffer-Big Sur State Park, Monterey County, California, by Gordon B. Oakeshott. 1951. 16 pp., 1 pl., 28 figs. Price 25¢.

12. Hydraulic filling in metal mines, by William E. Lightfoot. 1951. 28 pp., 15 figs. Price 50¢.

13. Geology of the saline deposits of Bristol Dry Lake, San Bernardino County, California, by Hoyt S. Gale. 1951. 24 pp., 1 pl., 2 figs. Price 35¢.

14. Geology of the massive sulfide deposits at Iron Mountain, Shasta County, California, by A. R. Kinkel, Jr., and J. P. Albers. 1951. 19 pp., 6 pls., 6 figs. Price 75¢.

15. Photogeologic interpretation using photogrammetric dip calculations, by D. H. Elliott. 1952. 21 pp., 9 figs. Price 50¢.

16. Geology of the Shasta King mine, Shasta County, California, by A. R. Kinkel, Jr., and Wayne E. Hall. 1951. 11 pp., 3 pls., 4 figs. Price 50¢.

17. Suggestions for exploration at New Almaden quicksilver mine, California, by Edgar H. Bailey. 1952. 4 pp., 1 pl. Price 25¢.

18. Geology of the Whittier-La Habra area, Los Angeles County, California, by Charles J. Kundert. 1952. 22 pp., 3 pls., 19 figs. Price 50¢.

19. Geology and ceramic properties of the Ione formation, Buena Vista area, Amador County, California, by Joseph A. Pask and Mort D. Turner. 1952. 39 pp., 4 pls., 24 figs. Price 75¢.

20. Geology of the Superior talc area, Death Valley, California, by Lauren A. Wright. 1952. 22 pp., 1 pl., 15 figs. Price 50¢.

21. Geology of Burruel Ridge, northwestern Santa Ana Mountains, California, by James F. Richmond. 1952. 1 pl., 11 figs. Price 50¢.

22. Geology of Las Trampas Ridge, Berkeley Hills, California, by Cornelius K. Ham. 1952. 26 pp., 2 pls., 20 figs. Price 75¢.

23. Exploratory wells drilled outside of oil and gas fields in California to December 31, 1950, by Gordon B. Oakeshott, Lewis T. Braun, Charles W. Jennings, and Ruth Wells. 1952. 77 pp., 1 pl., map. Price, map and report, $1.25; map alone, $1.

24. Geology of the Lebec quadrangle, California, by John C. Crowell. 1952. 23 pp., 2 pls., 10 figs. Price 75¢.

25. Rocks and structure of the Quartz Spring area, northern Panamint Range, California, by James F. McAllister. 1952. 38 pp., 3 pls., 13 figs. Price 75¢.

26. Geology of the southern Ridge Basin, Los Angeles County, California, by Peter Dehlinger. 1952. 11 pp., 1 pl., 7 figs. Price 50¢.

27. Alkali-aggregate reaction in California concrete aggregates, by Richard Merriam. 1953. 10 pp., 12 figs. Price 35¢.

28. Geology of the Mammoth mine, Shasta County, California, by A. R. Kinkel, Jr., and Wayne E. Hall. 1952. 15 pp., 9 pls., 5 figs. Price 75¢.

29. Geology and ore deposits of the Afterthought mine, Shasta County, California, by John P. Albers. 1953. 18 pp., 6 pls., 9 figs. Price 75¢.

30. Geology of the southern part of the Quail quadrangle, California, by Charles W. Jennings. 1953. 18 pp., 2 pls., 16 figs. Price 75¢.

31. Geology of the Johnston Grade area, San Bernardino County, California, by Robert Barton Guillou. 1953. 18 pp., 1 pl., 19 figs. Price 75¢.

32. Geological investigations of strontium deposits in southern California, by Cordell Durrell. 1953. 48 pp., 9 pls., 12 figs. Price $1.25.

33. Geology of the Griffith Park area, Los Angeles County, California, by George J. Neuerberg. 1953. 29 pp., 1 pl., 15 figs. Price 50¢.

34. Geology of the Santa Rosa lead mine, Inyo County, California, by Edward M. Mackevett. 1953. 9 pp., 2 pls., 3 figs. Price 50¢.

35. Tungsten deposits of Madera, Fresno, and Tulare Counties, California, by Konrad B. Krauskopf. 1953. 83 pp., 4 pls., 52 figs. Price $1.25.

36. Geology of the Palen Mountains gypsum deposit, Riverside County, California, by Richard A. Hoppin. 1954. 25 pp., 1 pl., 32 figs., frontis. Price 75¢.

37. Rosamond uranium prospect, Kern County, California, by George W. Walker. 1953. 8 pp., 5 figs. Price 25¢.

38. Geology of the Silver Lake talc deposits, San Bernardino County, California, by Lauren A. Wright. 1954. 30 pp., 4 pls., 18 figs. Price $1.00.

39. Barite deposits near Barstow, San Bernardino County, California, by Cordell Durrell. 1954. 8 pp., 4 pls., 1 fig. Price 50¢.

40. Geology of the Calaveritas quadrangle, Calaveras County, California, by Lorin D. Clark. 1954. 23 pp., 1 pl., 7 figs. Price $1.75.

41. Geology of the Angels Camp and Sonora quadrangles, Calaveras and Tuolumne Counties, California, by John H. Eric, Arvid A. Stromquist, and C. Melvin Swinney. 1954. 55 pp., 4 pls., 21 figs. Price $3.75.

42. Geology of mineral deposits in the Ubehebe Peak quadrangle, Inyo County, California, by James F. McAllister. 1955. 64 pp., 3 pls., 26 figs. Price $2.00.

43. Geology of a portion of the Elsinore fault zone, California, by John F. Mann, Jr. 1955. 22 pp., 2 pls., 5 figs. Price 75¢.

44. Bibliography of marine geology and oceanography, California coast, by Richard D. Terry. 1955. 131 pp., 2 figs. Price 75¢.

45. Exploratory wells drilled outside of oil and gas fields in California to December 31, 1953, by Charles W. Jennings and Earl W. Hart, 1956. 104 pp., 2 figs., map. Price $1.50.

46. Geology of the Huntington Lake area, Fresno County, California, by Warren B. Hamilton. 1956. Price 75¢.

STATE OF CALIFORNIA
GOODWIN J. KNIGHT, Governor
DEPARTMENT OF NATURAL RESOURCES
DeWITT NELSON, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO 11
OLAF P. JENKINS, Chief

AN FRANCISCO SPECIAL REPORT 46 AUGUST 1956

GEOLOGY OF THE
HUNTINGTON LAKE AREA
FRESNO COUNTY, CALIFORNIA

By WARREN B. HAMILTON

Price 75¢

Digitized by the Internet Archive
in 2012 with funding from
University of California, Davis Libraries

http://archive.org/details/geologyofhunting46hami

GEOLOGY OF THE HUNTINGTON LAKE AREA
FRESNO COUNTY, CALIFORNIA *

By Warren B. Hamilton

OUTLINE OF REPORT

Page
BSTRACT 3
NTRODUCTION 3
ETAMORPHIC ROCKS 7
RANITIC ROCKS 8
Mineralogy 9
Variations 10
Plutons 11
Joints 12
Flow structures 12
Aplite and pegmatite 12
Age of the granitic rocks 13
Weathering 13
Sequence of intrusion 13
Hybrid rocks 14
Contacts between granitic and metamorphic rocks 17
Modes of emplacement 21
OLCANIC ROCKS 23
LACIAL GEOLOGY 24
CONOMIC GEOLOGY 24
EFERENCES 25

Illustrations

Page
Plate 1. Geologic map of Huntington Lake area .... In pocket
igure 1. Index map of the Huntington Lake area 4
2. Geologic sketch map of Big Creek-Coyote Creek area 5
3. Geologic sketch map of Idaho Lake septum 10
4. Photo showing contorted pyroxene hornfels in septum near Idaho Lake 12
5. Photo showing Kaiser Peak from northwest 13
6. Photo showing contact between quartz monzonite of Mt. Givens pluton and quartz monzonite of Rodeo Meadow pluton 14
7. Photo showing contact between fine-grained quartz monzonite of Red Lake pluton and granodiorite of Tamarack Creek pluton 15
8. Photo showing xenoliths of granodiorite in quartz monzonite 16
9. Photo showing dark inclusions arrested in process of break-off from metamorphic rock 17
10. Photo showing contact between pyroxene hornfels and granodiorite 18
11. Photo showing Black Peak, a hornblende andesite plug 20
12. Photo showing small cirques on Mt. Givens 20
13. Photo showing Dinkey Lake 21
14. Photo showing Island Lake 22
15. Photo showing Cliff Lake 23
16. Photo showing cirque above Twin Lakes 24

ABSTRACT

The rocks of the Huntington Lake area, 160 square miles of the estern slope of the central Sierra Nevada, are dominantly granic. Two square miles of the area are underlain by metamorphic cks, chiefly quartzite and marble but including ferromagnesian ornfels and schist.

The placer gold deposits (Kaiser Diggings) of Kaiser Creek orthwest of the mapped area suggest the possibility that there ay be lode-gold deposits in Kaiser Peak area. Some of the ranitic rocks are suitable for use as monument and building one. Several tungsten deposits are present in the contact-altered arble pendants near Twin Lakes.

The granitic rocks vary from leucogabbro to alaskite and form velve separate plutons. Quartz monzonite and granodiorite are e most common rock types. Each of these plutons varies within itself, and the gradational variations are of considerable magnitude in some cases. In two plutons, for example, rock type varies from quartz diorite through granodiorite to quartz monzonite. In another pluton, content of ferromagnesian minerals varies from 2 to 19 percent. The typical granitic rock would be a hornblende biotite quartz monzonite.

The plutons are believed to compose two groups, an older western group and a younger eastern group. At least within the eastern group, some successive intrusions were emplaced before their predecessors were completely solid, and within that group most plutons were intruded in order of increasing content of silica and alkalis. Emplacement of plutons was primarily by physical displacement.

Contact effects of granitic magmas on metamorphic rocks include contact metamorphism, granitization, assimilation, and the formation of stable hybrid rocks such as the dark inclusions of the granitic rock.

Volcanic rocks of probable Tertiary age occur as small masses forming four peaks. Three of these masses are intrusive (two are trachybasalt, one is andesite), and the fourth is a remnant of trachybasalt flows.

Much of the area was covered by ice several times during the Quaternary epoch.

INTRODUCTION

The Huntington Lake area is in Fresno County in the upper-middle elevations of the western slope of the central Sierra Nevada about 50 miles northeast of the city of Fresno. The area is irregular in outline with maximum dimensions of 15 miles east-west and 13 miles north-south and has an area of 160 square miles. Most of the northern and eastern boundaries of the area are formed by, respectively, parallel 37° 20′ North and meridian 119° 00′ West, and the area is thus in the east-central part of the Kaiser quadrangle of the U. S. Geological Survey.**

Huntington Lake is reached by State Highway 168 from Fresno. A road, paved in part, continues northeast and east from the end of Highway 168 at Huntington Lake over Kaiser Pass to Florence Lake, just east of the map area. Several U.S. Forest Service and Southern California Edison Company unimproved roads extend short distances into the area from Highway 168 and its continuation.

The town of Big Creek is the only permanent settlement in the area, but there are several small summer communities along the north shore of Huntington Lake, the largest of which is Lakeshore.

Geologic Story of the High Sierra Nevada. The Sierra Nevada of California, with its unbroken length of 400 miles of mountain wilderness, is the most imposing mountain block in the United States. Here, in the rocks and majestic landscape, the story of nearly half a billion years is recorded.

The peaks, canyons and meadows of the High Sierra present a spectacular exhibition of the work of the forces that act within the earth's crust and upon the earth's surface. Rocks formed from sands and muds on the floors of ancient seas were buried miles deep by lava flows and more sediments, crumpled by slow titanic forces, and changed by heat and shear to metamorphic

---

Prepared in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Department of Geology, University of California, Los Angeles. Manuscript received for publication July 1951.

** The area includes parts of the new Shuteye Peak, Kaiser Peak, Shaver Lake, and Huntington Lake 15-minute quadrangles. These maps were not available at the time of the field and office work.

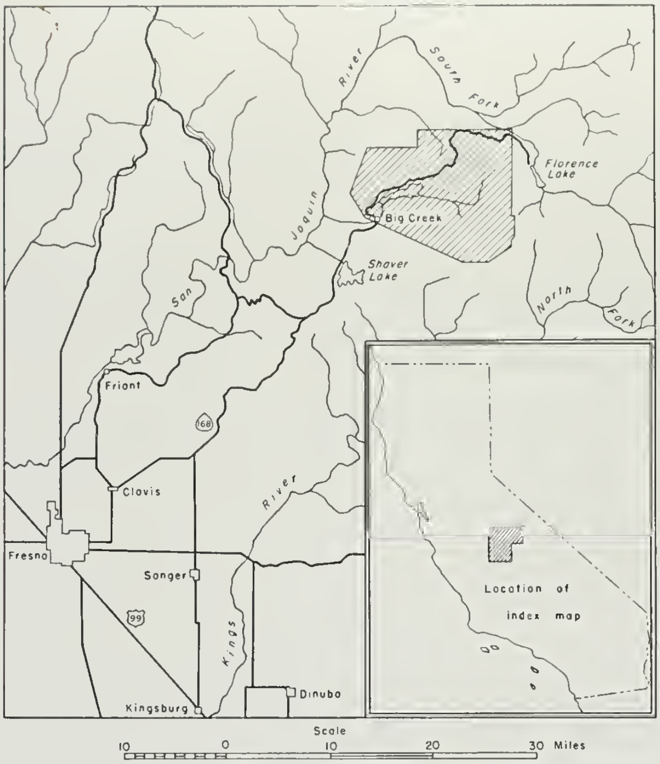


Figure 1. Index map of the Huntington Lake area.

rocks. Masses of semi-molten magma, formed from deeper, hotter rocks, rose upward into the metamorphic rocks and slowly crystallized to granite.

These granites and rocks from the ancient seas were raised gradually while erosion carved them incessantly, and the result has been the High Sierra. Yet high though these rocks now stand, several miles of rock were eroded to expose the rocks we now see. Most of this erosion was done by running water and slowly moving soil, but the landscape was profoundly changed only yesterday by the work of frost and moving ice.

The oldest rocks of the Sierra region were formed 400 million years ago when a broad sea covered much of the West. Into this sea, rivers brought sand and silt eroded from ancient mountains. Lava periodically flowed out on the sea floor and was buried by later sediments. Sediment and lava accumulated intermittently and irregularly for nearly 300 million years as the sea floor kept sinking to allow a great quantity of rock to accumulate. Interruptions of compression folded and broke the rocks at different times and various places. Finally, the sediments and lavas totaled miles in thickness.

About 100 or 120 million years ago, great compressive forces squeezed the Sierra region, slowly crumpling and shearing the rocks into ever-tightening folds, and thrusting the rocks over one another. This squeezing thickened the pile of lavas and sedimentary rocks and forced a large part of them miles beneath their former depths, down into hotter parts of the earth's crust. Rocks that had been laid down on the sea floor were crystallized (metamorphosed) by the high stresses and temperatures to form coarse-grained rocks. Limestone became marble, sandstone became tough quartzite, shale became platy schist.

Even greater changes took place in the rocks depressed most deeply. The temperatures of these rocks were so high that they were partly melted. According to one theory for the origin of granites, tens of thousands of cubic miles of rocks—sediments, lavas, and the still more ancient rocks upon which they had been laid—were transformed beneath the present Sierra Nevada into hot mushes of crystals and molten rock. The fluid rock rose into the folded metamorphic rocks above in hundreds of separate masses, shouldering aside the solid rocks, incorporating material from solid rock into the mush, and slowly cooling and solidifying to form the coarse gray speckled rock we know as granite.

Most of the Sierra is made of granite. Formed miles below the surface, it has been exposed by erosion. Granite seen from a distance appears to be of one monotonous type, but actually it varies greatly. Each of the hundreds of separate granite intrusions in the Sierra differs from its neighbors, although there is much repetition of a dozen or so common types of granite. Most of the granite intrusions vary within themselves; few are so uniform that marked variations cannot be discerned in them. Some granite contains no dark mineral grains but only white ones, whereas half the grains of other granite are black minerals. Most is coarse, but some is fine-grained with a pepper-and-salt appearance. Some granite contains big rectangular crystals of pink feldspar.

When examined closely, many of the granites of the Sierra are seen to have their mineral grains and long dark inclusions oriented into layers, usually nearly vertical. These layers show how the granites moved upward when partly molten, dragging past their margins and forming the streaked-out bands much as might taffy.

A study of contacts between granite and metamorphic rocks tells much of chemical reactions between semiliquid granite and solid metamorphosed rocks when their temperatures were a thousand degrees Fahrenheit. Some minerals from the solid rocks were melted and added to the granite fluid, whereas other types of mineral grains were rafted bodily into the liquid.

The problem of the origin of granite and the means of emplacement of granite intrusions is one of the most fundamental, most argued, and least understood problems of geology. Theories with varying support and plausibility range widely between flatly contradictory extremes. No explanation yet given can account satisfactorily for all of the observed features. Much of the evidence that will help give the ultimate solution to the problem may come from the High Sierra, where the results of granite-forming processes are so superbly exposed in bare glacier-polished rock.

A great mountain system, very different from the present Sierra, was formed after the period of compression and granite formation. Rock eroded from these mountains was carried by rivers far to the east and to the western sea, then closer than now, and by the beginning of Eocene time 60 million years ago the ancestral Sierra had been eroded to rolling upland much more subdued than the present mountain chain.

The Sierra in its present form—a long continuous mountain block, sloping gently toward the west (though gashed by mile-deep canyons) and steeply toward the east—came into being in the relatively recent geologic past. A series of fractures, or faults, was formed along the present Owens Valley, and the Sierra and the Owens

Valley gradually moved apart along these faults. The vertical movement on these faults has totaled several miles; although it is not certain whether the Sierra block was pushed up past the Owens Valley or the Owens Valley settled down as a keystone in a gigantic arch, the former motion was probably the dominant one.

The movement is still going on. In 1872, the sudden offset of 25 feet on a small Owens Valley fault caused a severe earthquake. Much of the total Sierra fault uplift has resulted from such abrupt displacements of a few feet with attendant earthquakes, but an important part of the offset has been gradual: too slow to be observed, yet of great magnitude because of the enormous spans of time it has taken. Earthquakes were probably no more frequent in the past than they are now.

Semi-tropical forests covered the Sierra of 60 million years ago, and rivers wandered through the ranges of low hills. Gradually the earth's climate became cooler and the Sierra rose intermittently higher; finally, within the last million years, snow began to accumulate for year after year. The snow packed into ice and, forming small glaciers, began to move downhill under its own weight. The high country glaciers grew and joined in the valleys to push tongues of ice tens of miles down the major valleys; in much of the High Sierra, only the peaks stood above broad glacial caps.

The climate changed and became warmer. The ice receded: still the glaciers flowed downhill, but each year more ice was melted than was added, and the glaciers dwindled and disappeared. The vast quantities of rock carried in the ice after being gouged by the moving glaciers from peaks and valleys were dropped as the ice melted. The glacier cycle has been repeated three or four times, with each cycle a brief period of rapid glacier growth followed by retreat and a long ice-free period.

The most recent major glaciers were at their maximum only ten or fifteen thousand years ago—only a moment, speaking geologically. The glaciers then shrank rapidly and disappeared completely before 3,000 B. C. The small glaciers now present in the High Sierra have been formed in the generally cooler climate of the last several thousand years; now the climate is warming again, and the glaciers are melting so rapidly that another fifty years of warm weather will probably remove them completely.

Glaciers profoundly changed the Sierra landscape. Cliffs and steep valley walls were gouged and quarried by the ice. Near their heads, the glaciers formed immense amphitheaters, now strewn with lakes; lower

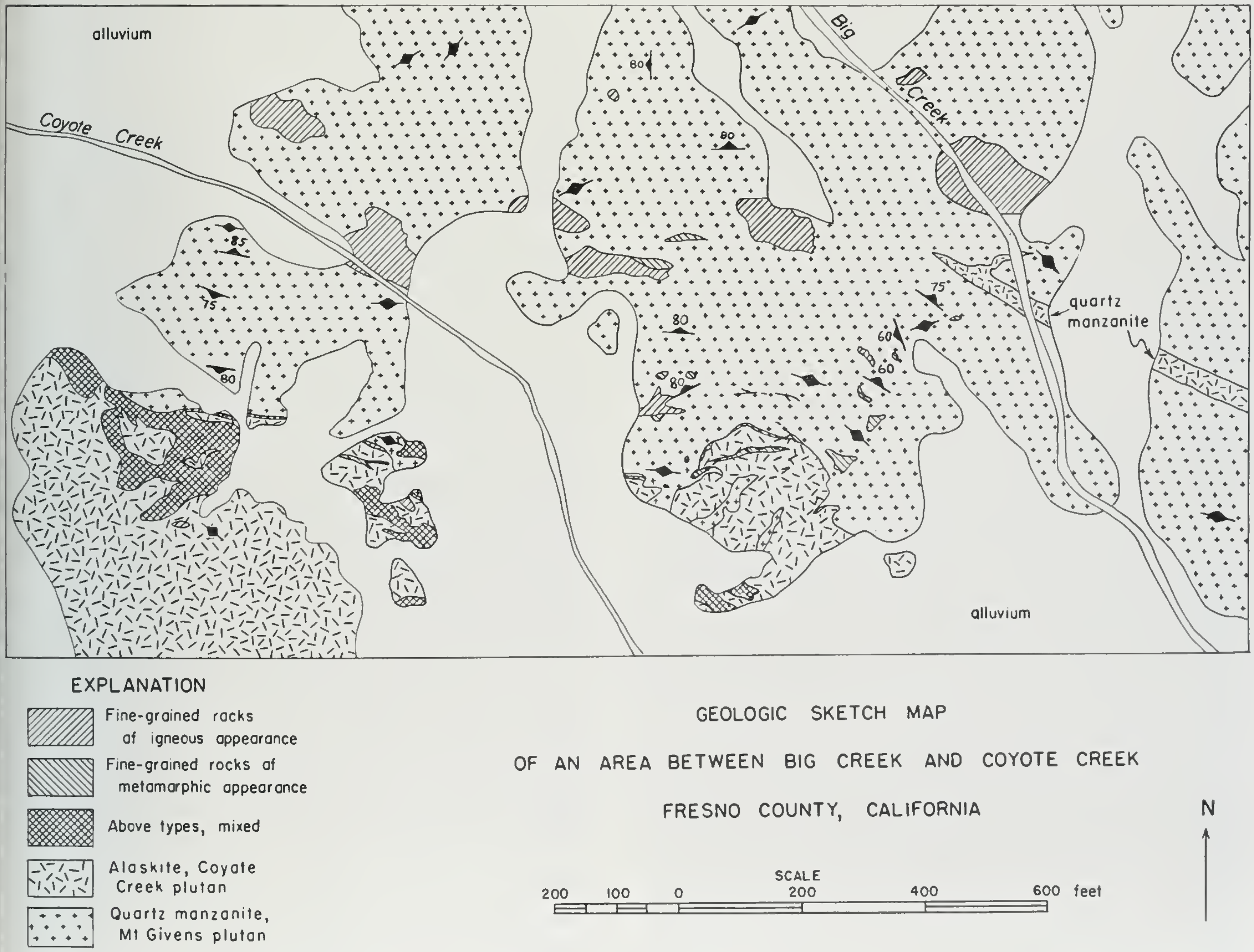

alluvium
Coyote Creek
Big Creek
80
85
75
80
80
80
75
80
60
60
80
quartz manzanite
alluvium
EXPLANATION
Fine-grained rocks of igneous appearance
Fine-grained rocks of metamorphic appearance
Above types, mixed
Alaskite, Coyote Creek pluton
Quartz manzanite, Mt Givens pluton
GEOLOGIC SKETCH MAP
OF AN AREA BETWEEN BIG CREEK AND COYOTE CREEK
FRESNO COUNTY, CALIFORNIA
N
SCALE
200 100 0 200 400 600 feet

Figure 2. Geologic sketch map of Big Creek-Coyote Creek area.

down, debris melted from the ice was deposited to form broad meadows. Nearly all of the beautiful lakes of the High Sierra are products of glaciation. Many fill basins scooped by ice from solid granite; others dot the alpine meadows, dammed by ridges of debris from the melted ice.

In the brief period since the last large glaciers melted, frost has made other great changes in the landscape. Water freezing into cracks in the rocks has pried loose blocks to fall from peaks and cliffs to form huge talus piles. Where slopes are too gentle to permit the frost-quarried blocks to fall, chaotic jumbles of frost-heaved blocks cover the surface.

This is the story of the High Sierra. Half a billion years of ceaseless change, changes going on now as they have gone on in the past, changes that have given us the grandeur of the High Sierra.

Field Work and Acknowledgments. The field work for this report was done during the summers of 1948, 1949, and 1950. Mapping was done on U. S. Forest Service vertical aerial photographs on a scale of about 3 inches to the mile and the base map used for this report was compiled by crude methods from the photographs. Control was provided by triangulation points of the Kaiser quadrangle and by the triangulation network of the Southern California Edison Co. The writer was provided with copies of charts of the Land Department of that company. Distortion of the base map is greatest in the southeastern part of the area.

The writer is particularly indebted and grateful to Cordell Durrell, Kenneth D. Watson, and George J. Neuerburg for assistance and discussion in many phases of the work. Advice in the field and laboratory was also given the writer by James Gilluly, John C. Crowell, and Anders Kvale.

Office and laboratory equipment and space and the preparation of thin sections were provided by the Department of Geology, University of California, Los Angeles.

Previous Work. The only extensive previous work in this area is that of Krauskopf (1953). This consists of excellent reconnaissance mapping of a large area to the south and southeast of the Huntington Lake area and includes that part of this area which is south of Latitude 37° 12′. Numerous mines are described in detail.

Chesterman (1942) made a large-scale map of a small mass of contact-metamorphosed limestone at Twin Lakes.

Mayo (1941) made a subjective structural map of the central Sierra Nevada on a scale of 8 miles to the inch which included most of this area.

Other geologic work outside of the area but in the section across the Sierra through Huntington Lake is that of Knopf (1918) and Bateman (unpublished) in the Sierra crest and east slope region and that of Macdonald (1941) in the western foothills.

Topography. The Sierra Nevada is about 60 miles wide across this part of its northwest trend. Elevations of the range increase gradually but irregularly from a few hundred feet at the eastern edge of the San Joaquin Valley to over 13,000 feet at the main Sierra crest, then decrease abruptly to 5,000 feet in the Owens Valley. The Huntington Lake area, with its elevation range of from 5,000 to 10,600 feet, lies in the upper-middle elevations of the western slope.

The dominant topographic feature of the Huntington Lake area is Kaiser Crest which rises an average of about 3,000 feet above Huntington Lake to an altitude of over 10,000 feet. The crest forms a broad asymmetric bowl open to the south, steeper to the west and north of Huntington Lake than to the east. The bowl is drained by Big Creek, which joins the San Joaquin River southwest of the map-area. The outside slope of the crest drains in part to the South Fork of the San Joaquin River and in part to the San Joaquin itself. The southeastern part of the area is drained by Dinkey Creek to the Kings River and via Helms Creek to the North Fork of the Kings River.

Most of the area is higher than Huntington Lake with its elevation of 6,950 feet, but the small segment between the lake and the town of Big Creek drops to 5,000 feet, and the northeast corner of the area extends down to 6,500 feet on the South Fork of the San Joaquin River. The highest peak in the area is Mt. Givens with an elevation of 10,643 feet.

Much of the area was covered several times by Quaternary glaciers with resultant alpine glacial erosion and deposition. The non-glaciated part of the area—chiefly the lower part of the area north and south of Huntington Lake—has a heavy soil and forest cover.

The deep gorges of the western Sierra have cut into the area only in the southwest where the head of Big Creek gorge extends to the lower end of Huntington Lake.

Climate and Vegetation. The climatic and floral changes within this area are due chiefly to altitude.

Climatic data for the area are given by the U. S. Department of Agriculture (1941). Slightly generalized, these show the January average temperatures to be 40° and 29° F for Big Creek and Huntington Lake, respectively, and July averages to be 72° and 61°. Average annual precipitation totals about 30 inches at each station, with 90 percent of it falling during the months November through April at Big Creek and 80 percent at Huntington Lake. Above Huntington Lake, temperatures and total precipitation should decrease with increasing elevation, and the proportion of the total precipitation falling during the summer should increase.

In the over-simplified concept of life zones, the Huntington Lake area is included in the Transition, Canadian, and Hudsonian zones. The higher parts of the area are mostly open, semi-barren, with mountain juniper and scrubby white-bark pine as the chief trees. Below this zone, most of the area except for bare glaciated rock is heavily forested. The highest part of the heavy forest is of white pine, red fir, and hemlock, with lodgepole pine on flats. Next lower is the nearly pure fir forest of red and white fir. Below this is the middle Sierran mixed forest of yellow, sugar, and Jeffrey pines, white fir, incense cedar, and, in the lowest parts of the area, black oak. Manzanita, deer brush, and chinquapin are the most common shrubs. Sages are important on some of the high dry areas. Meadows are at all but the lowest elevations.

Regional Geology. Western North America can be divided grossly into two major Paleozoic and Mesozoic tectonic belts, between which the boundary varied much at different geologic times. In the east, the Laramide belt received geosynclinal and shelf sediments, mostly carbonate and clastic rocks, commonly thickest in the late pre-Cambrian and early Paleozoic eras. These rocks were deformed by folding and thrusting mostly in late Cretaceous and early Tertiary periods; here, metamorphism and granitic intrusions were of minor importance only.

The western geosynclinal Nevadan belt received its thickest sediments in the late Paleozoic and Mesozoic eras. Volcanic and pyroclastic rocks are abundant in the stratigraphic column, and the most common sedimentary rocks are slate, silt, and graywacke. The rocks of the Nevadan belt were in many areas subjected to intermittent deformation during the geosynclinal history, but the major deformation of most of the belt occurred in the Jurassic and Cretaceous periods. The rocks of most of the belt were subjected to regional metamorphism which varied greatly in grade, and batholithic granitic complexes were developed extensively. The largest of the complexes is the Coast Range batholith of British Columbia and Alaska. The Sierra Nevada batholith has an exposed length of more than 300 miles and a width of as much as 70 miles.

Along the western edge of the central Sierra Nevada, Upper Cretaceous and Tertiary sediments of the San Joaquin Valley lap onto the Sierra bedrock complex of metamorphic and granitic rocks, here chiefly metasedimentary and meta-volcanic rocks with intrusions of late Mesozoic quartz diorite. Northeastward, the metamorphic rocks decrease in abundance and the increasingly abundant granitic rocks form a broad belt with an average composition of granodiorite or quartz monzonite. The Huntington Lake area is near the center of this broad belt of granitic rocks.

At the latitude of Huntington Lake, the broad granitic belt is bounded on the northeast by a long band, several miles wide, of meta-volcanic rocks. From this band to the main Sierra crest are many granitic masses, many bounded by thin discontinuous septa of metamorphic rocks. A few miles northeast of the crest, metamorphic rocks become abundant.

The steep eastern slope of the Sierra is the erosion-modified expression of the structural boundary of the complex graben of the Owens Valley.

The granitic rocks of much of the southern Sierra Nevada are mostly in steep-walled discordant intrusive plutons.* Plutons vary in exposed size from a few acres to several hundred square miles, and the Sierra Nevada batholith probably is a composite of hundreds of plutons. Rock types in adjoining plutons can be greatly different, and individual plutons can vary much within themselves. Granodiorite and quartz monzonite are the most common types, granite and quartz diorite are abundant, and diorite, gabbro and alaskite are common.

Plutons were intruded mostly following strong deformation and moderate regional metamorphism. Contact metamorphism was intense about many of the plutons, showing that temperature gradients from plutons to wall rocks were steep and that the plutons brought heat upwards with them. Contacts are complexly discordant in detail; this is true for many contacts between plutons as well as for contacts between granitic and metamorphic rocks. Contacts are commonly remarkably sharp, and less than an inch of gradation and reaction textures separates opposing rock types across most of the contacts superbly exposed by glaciation in the High Sierra. Although assimilation added much material to the granitic plutons, most of the granite was clearly intrusive in mobile form into the levels at which the rocks are now exposed.

METAMORPHIC ROCKS

Metamorphic rocks underlie about 2 square miles, or a little over 1 percent, of the Huntington Lake area and are confined to the area north and northwest of Huntington Lake. Of the metamorphic rocks, about 5 percent are schists and hornfelses containing appreciable quantities of ferromagnesian minerals, 20 percent are marbles and calc-silicate hornfelses, and 75 percent are quartzites.

The masses of metamorphic rocks are all in contact with the rocks of the Kaiser Peak pluton, a body of granitic rocks discussed in detail on later pages. The marbles and most of the ferromagnesian schists and hornfelses occur in a septum bounding the pluton on the northeast, whereas most of the quartzites occur within the pluton as irregular masses that vary in size from a few square feet to a square mile.

All of the metamorphic rocks have had a complex development in which the results of strong contact metamorphism have been superimposed on and in part have obliterated the results of regional metamorphism.

Quartzite. Most of the quartzite is medium-grained, white, light gray, or pale pink, and contains only negligible quantities of dark minerals, usually biotite. The quartz is accompanied by minor quantities of potash feldspar with lesser quantities of sodic plagioclase. All of the quartzite is completely recrystallized; relic clastic texture was recognized only in small rounded grains of zircon. Quartz crystals are flattened and show a slight crystallographic orientation within the foliation.

Much of the quartzite of the septum between the Kaiser Peak and Mt. Givens plutons contains minor quantities of clinopyroxene and plagioclase. This quartzite rarely contains biotite.

Meta-conglomerate occurs with the quartzite mass 2 miles west of Kaiser Peak. In the contorted conglomerate, the pebbles, now coarse-grained quartzite, have been deformed to an elongation of about two to one, and are set in a matrix of biotite-rich quartzite.

Ferromagnesian schists and hornfelses are closely associated with quartzite in the many small masses of metamorphic rocks near Kaiser Peak but are rare in the large masses of quartzite. Minor amounts of quartzite occur with the crystalline limestone and ferromagnesian hornfels and schist of the Twin Lakes-Idaho Lake septum.

Frost heaving has covered most of the quartzite masses with angular blocks of displaced quartzite so that exposures of quartzite in place are uncommon. The quartzite of the areas of good exposure occurs in bands a few feet or a few tens of feet thick, and this banding is in most places parallel to the foliation, both having high to moderate dips. Some small areas of quartzite show several intersecting directions of foliation of roughly equal quality.

The quartzites must have been sandstones before metamorphism. Biotite, potash feldspar, and sodic plagioclase now present represent argillaceous material, whereas diopside and calcic plagioclase represent calcareous impurities.

---

* The word "pluton" is used to mean a mappable body of granitic rocks; no specific meaning is intended as to origin or means of emplacement of the body.

Marble and Calc-silicate Hornfels. Marble and calc-silicate hornfels in the Huntington Lake area are restricted to the septum between the Mt. Givens and Kaiser Peak plutons where, in the vicinity of Twin Lakes, these metamorphic rocks occur in a mass about 1⅔ miles long and a quarter of a mile wide.

Coarse white or gray calcite marble is the most important rock type, although medium-grained white dolomite marble is also abundant. The mineralogy of these marbles and the calc-silicate rocks has been described at length by Chesterman (1942).

Calc-silicate hornfelses of considerable variety occur with the marbles, in part interbedded with them and in part in discrete areas. Among the more abundant calc-silicate minerals are wollastonite, diopside, grossularite, plagioclase, and spinel. Several small areas of hedenbergite-andradite-plagioclase-magnetite skarn containing minor scheelite were noted by Chesterman (1942). Quartzites and ferromagnesian hornfelses are present in minor masses with the crystalline limestone.

Foliation in the marble is steep and strikes roughly parallel to the margins of the septum. Several isoclinal folds were recognized but could be traced for only short distances. Calcite grains of the marble are much sheared and elongated within the foliation, whereas the calc-silicate minerals in general show random orientation.

Pyroxene Hornfels. Pyroxene hornfels makes up most of the septum of metamorphic rocks above Idaho Lake and is present in lesser quantities in many of the other masses of metamorphic rocks.

The hornfelses are of superficially uniform appearance. When fresh, all are medium-grained, light green in color (the color due to the green monoclinic pyroxenes present), and finely banded, with pyroxene-rich bands alternating with bands of chiefly white minerals.

Most of the pyroxene is hedenbergite but diopside is abundant and augite is probably present. (These minerals form a completely gradational series and are assigned these names on the basis of their pleochroism and color in thin section.) Pyroxene constitutes an average of about a quarter of the hornfels.

Light-colored minerals in these hornfelses are quartz, plagioclase (andesine or oligoclase) and potash feldspar. These minerals occur in widely varying proportions. Potash feldspar is usually present in considerably larger crystals than those of the other minerals.

Sphene, commonly present in small egg-shaped crystals, and magnetite are the common accessory minerals in these hornfelses. Brown garnet forms augen varying from an inch to several feet in length in some of the hornfels.

Much of the hornfels above Idaho Lake is isoclinally folded and intricately contorted with the steep foliation striking parallel to the trend of the septum.

Thin crystalloblastic lenses up to several inches long of quartz and potash feldspar are common in the hornfels and are particularly abundant in the crests of the intricate small-scale folds of the rock. The material of the lenses is shown by its textural relations to the surrounding hornfels to be in part of local origin, representing the recrystallization and segregation of material already present. Many of the lenses contain hornblende derived by alteration of metamorphic clinopyroxene or augite clearly of metamorphic origin.

The parentage of these rocks is uncertain. Those with high plagioclase content may have come from basic volcanic rocks but the abundance of potash feldspar and quartz in many specimens and the presence of brown garnet suggest that the material represented by many of the hornfelses came from calcareous sedimentary rocks having varying proportions of argillaceous and arenaceous material.

Hornblende and Biotite Schist. Schists carrying biotite or hornblende or both are present in the septum above Idaho Lake, are common in many of the small masses of metamorphic rocks near Kaiser Peak, and are present in small quantities in most of the quartzite masses.

These medium-grained rocks are gray to black in color and consist of bands of pagioclase (typically oligoclase), potash feldspar, and quartz alternating with black bands of hornblende or biotite. Potash feldspar is subordinate to the other light minerals in all specimens examined but is in considerably larger crystals than are the other minerals, and is much more abundant with hornblende than with biotite. Plagioclase and quartz occur in proportions varying from half plagioclase and half quartz to almost entirely quartz. Sphene, the most common accessory mineral, is present in small egg-shaped grains.

The hornblende and biotite schists occur together in alternating bands varying from a fraction of an inch to a few tens of feet thick. Hornblende schist is the more abundant type in the Idaho Lake septum, whereas biotite schist is the more abundant in most of the other areas of metamorphic rocks. All compositions intermediate between biotite schist, biotite quartzite, and quartzite may be found.

In the Idaho Lake septum, the schists, like the pyroxene hornfels, are intricately contorted.

The schists probably had their origin as argillaceous and arenaceous sediments containing only minor calcareous material.

Age of the Metamorphic Rocks. No fossils have been found in the metamorphic rocks of this area. Of the original rock types in the sedimentary section, little remains but the meta-sandstone, so that the over-all character of the original stratigraphic section is unknown; even the parentage of some of the rocks is uncertain. Metamorphic rocks elsewhere in the central Sierra have been dated as Ordovician, Carboniferous, Triassic, and Jurassic. As the rocks of the Huntington Lake area might belong to any one or to any combination of these periods, or even to none of them, no suggestions as to the age of the metamorphic rocks will be made beyond the fact that they are older than the granitic rocks which are of probable Jurassic or Cretaceous age.

GRANITIC ROCKS

Nearly 99 percent of the basement rocks of the Huntington Lake area are granitic. These rocks are similar in many respects. Few distinctions between rock types can be made in the field at distances of more than a few tens of feet, and some distinctions can be made only by careful study of hand specimens and thin sections. The granitic rocks are mostly leucocratic to mesocratic, gray in color, and have a speckled appearance with black

Table 1. Mineralogic composition of the granitic rocks of the Huntington Lake area.

Figures give minimum and maximum percentage, slightly generalized, based upon visual estimates. Minor accessory minerals are not included. Percent of plagioclase is shown under most abundant type; other types present are indicated by "x".

Mineral / Pluton or rock type	Quartz	Potash feldspar	Plagioclase feldspar								Total ferro-magnesian minerals	Hornblende	Biotite	Number of thin sections
			Albite	Sodic oligoclase	Calcic oligoclase	Sodic andesine	Calcic andesine	Sodic labradorite	Calcic labradorite	Sodic bytownite				
Alaskite (Dinkey Lake, Coyote Creek, Rancheria Creek) plutons	25-35	35-45	20-35	x							½-1	musc. ¼-½	¼-½	7
Granite of Dinkey Lake pluton	20-25	40-50	x	25-35							1-3	musc. ½-1	½-2	3
Sheepthief Creek pluton (granite)	15-25	50-70		x	10-30						2-5	½-2	2-4	5
Rodeo Meadow pluton (quartz monzonite)	20-25	30-40			35-45						3-5	tr.	3-5	3
Red Lake pluton (quartz monzonite)	20-25	25-50			x	25-50					2-7	tr.	2-7	14
Mt. Givens pluton (quartz monzonite and granodiorite)	15-25	15-50			x	25-55	x				2-19	tr.-15	2-7	46
Kaiser Peak pluton (quartz monzonite, granodiorite, and quartz diorite)	20-35	10-40			x	25-50					3-10	tr.-5	3-6	45
Tamarack Creek pluton (quartz monzonite, granodiorite, quartz diorite)	15-20	15-35			x	40-60	x				7-10	3-7	3-4	3
Helms Creek pluton (granodiorite)	15-20	15-25				45-55					10-15	4-10	5-9	5
Huntington Lake pluton (granodiorite, quartz diorite)	10-20	2-30				x	45-60				7-20	3-14	4-7	14
Leucogabbro near Nellie Lake	5	1						x	x	69	25	15	augite 10	1

grains of hornblende and biotite seattered in a white matrix of quartz and feldspars.

The granitic roeks of the Huntington Lake area form 12 masses bounded more or less sharply against neighboring masses. Each of these masses, or plutons, varies within itself.

Mineralogy

The plutons of granitie roeks of the Huntington Lake area are composed mainly of varying proportions of quartz, plagioclase, and potash feldspar. Most rocks of the plutons eontain hornblende, a few contain muscovite, one contains augite, and all but one eontain biotite.

Although the proportions of the different minerals in varous roek types vary widely between plutons, the minerals show many similarities in most plutons.

The quantitative mineralogic composition of the granitic rocks is shown in table 1.

The variations in these figures for the roeks of any one pluton refleet the variations of the roeks themselves. The rocks of each pluton are different from those of adjoining plutons, but gradual variations within individual plutons are of greater magnitude in some eases than are variations between plutons.

The granitic roeks of the Huntington Lake area vary from leueogabbro to alaskite. The typieal, or median, roek would be a quartz monzonite containing approximately 20 pereent quartz, 30 percent potash feldspar, 40 pereent sodic andesine, 4 percent hornblende, and 6 percent biotite.

The granitic rock types have been named on the basis of their feldspar ratios. The divisions between quartz diorite, granodiorite, quartz monzonite and granite are made at the arbitrary ratios of plagioclase to alkali feldspars of, respectively, 4:1, 5:3, and 3:5. Alkali feldspar is potassic in all these rocks except the granite of the Dinkey Lake pluton, in which nearly half the feldspar is sodie oligoclase. Alaskite is eomposed of quartz, potash feldspar, and albite, with less than 1 pereent of aeeessory minerals. Leucogabbro is composed mostly of calcie plagioclase.

Quartz. Quartz is anhedral in all rocks, and occurs as irregular grains and stringers in most plutons. The color of quartz is icy gray in all roeks except the alaskites, in which it is smoky gray-brown. Mosaie extinction is well developed in quartz of nearly all rocks except those of the southeastern part of the area.

Potash Feldspar. The division of potash feldspar into orthoclase and microcline is not feasible. Nearly all of the potash feldspar appears patchy under crossed nicols, with patches of grid-twinned microcline in non-twinned orthoelase.

Most of the potash feldspar is microperthitic. It is present mostly as anhedral grains, poikilitically enclosing grains of all other minerals. Potash feldspar is white in all rocks exeept the alaskites, in which it is a very pale orange, and in parts of the Kaiser Peak pluton, in whieh it is a very pale lavender.

Plagioclase. Plagioclase crystals are eommonly subhedral, tabular, and smaller than the crystals of potash feldspar. In fresh specimens, the eolor of plagioelase varies from medium gray in leucogabbro to light gray in the quartz diorite of the Huntington Lake pluton and white in most of the other plutons.

Plagioclase shows the usual rough correlation in composition with rock type. The more silieeous the rocks, the more sodic the plagioclase.

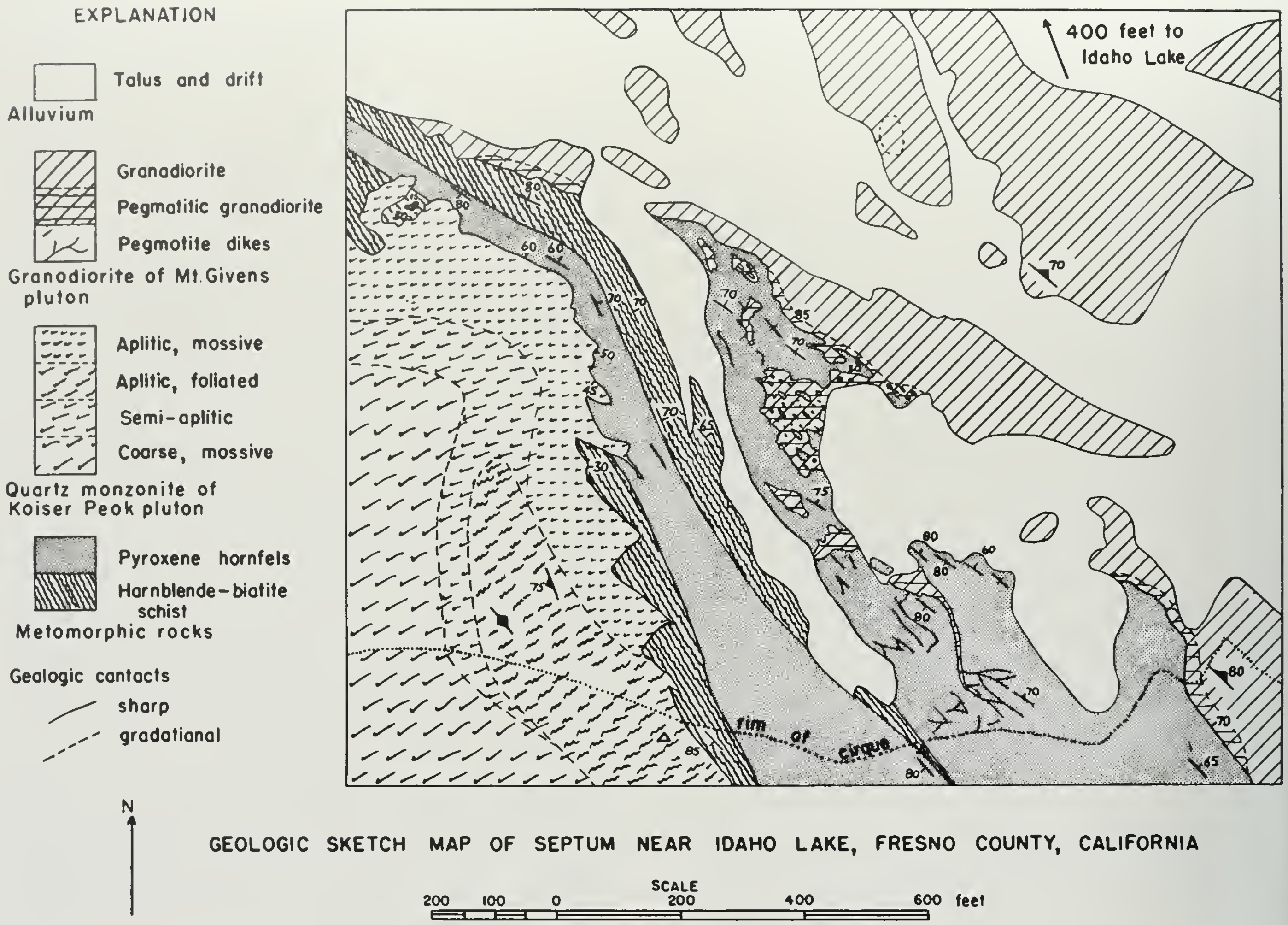


Figure 3. Geologic sketch map of Idaho Lake septum.

The plagioclase of all rocks is zoned, with a general gradation from a calcic interior to a sodic rim. The gradation commonly represents a change in anorthite content of 10 or 20 percent. Unconformities and oscillations in the zoning are abundant.

Biotite. Biotite occurs commonly in subhedral books with well-developed basal pinacoids. Biotite is black in hand specimen, and brown in thin section with pleochroism X pale yellow brown, Y and Z dark olive brown.

Hornblende. Hornblende crystals are commonly prismatic with well-developed prism faces and without terminations. Hornblende is black in hand specimen, green in thin section with pleochroism X pale brown, Y olive green, and Z green.

Muscovite. In the several plutons in which it is present, muscovite occurs in small raggedly anhedral grains and in sheaflike radial aggregates.

Augite. Augite is present only in the small mass of leucogabbro. It is greenish black in hand specimen and a very faint brown, non-pleochroic, in thin section.

Minor Accessory Minerals. Magnetite is present in all of the granitic rocks, and occurs in equidimensional grains. Sphene is present in all rocks except the alaskites, mostly as euhedral wedges. Tiny euhedral prisms of apatite and zircon are present in all of the granitic rocks. Euhedral crystals of zoned allanite are sparsely distributed in all rocks except the alaskites. Red garnet is common in the alaskites.

Variations

The rocks of the granitic plutons vary within individual plutons and between plutons. Variations within plutons are in many cases of considerable magnitude, as is shown in the mineral composition table and by the distribution of rock types within plutons as shown on the geologic map.

The relative abundance of the different granitic rock types of the area is shown by the following approximate percentages of the total area of granitic rocks occupied by each rock type: alaskite, 5%; granite, 4%; quartz monzonite, 47%; granodiorite, 33%; quartz diorite, 11%; leucogabbro, 0.02%.

In general, as the soda-lime feldspar content of the rocks increases, so does the total content of ferromagnesian minerals. The proportion of hornblende to biotite tends to increase with the total content of ferromagnesian minerals and soda-lime feldspar. The composition of plagioclase feldspar is closely related to rock type.

Plutons

Mt. Givens Pluton. The 74 square miles of the Mt. Givens pluton that are within the map area are but a small fraction of its total extent; Krauskopf has mapped it extending far to the southeast and the writer has found it northeast of the map area.

Within this area, the rock type of the Mt. Givens plutons varies from biotite hornblende granodiorite to biotite quartz monzonite. The content of dark minerals varies from nearly 20 percent in the northeast to 2 percent in the southeast. Grain size varies from coarse to medium. Plagioclase varies from calcic andesine zoned to sodic andesine in the northeast to sodic andesine zoned to calcic oligoclase in most of the rest of the pluton. Quartz and potash feldspar are anhedral throughout the pluton, and the latter is also poikilitic. Square-tabular phenocrysts of potash feldspar are abundant near the Coyote Creek alaskite contact. Ferromagnesian minerals are mostly in distinct crystals, but their quality varies from that of large euhedral hornblende prisms in the northeast to small ragged biotite crystals in the southeast.

Kaiser Peak Pluton. Thirty square miles of the Kaiser Peak pluton is within the northwestern part of the map-area. The rocks are relatively leucocratic quartz diorite, granodiorite, and quartz monzonite. In all types, sodic andesine is the dominant plagioclase.

The rocks of this pluton are texturally unique among the granitic rocks of the area, although similar rocks have been observed by the writer elsewhere in the Sierra. Potash feldspar is mostly in well-shaped crystals instead of mostly in poikilitic anhedral grains as in the other rocks of similar composition. Part of the pluton is porphyritic with large rectangular crystals of potash feldspar. Quartz is present mostly in egg-shaped aggregates of intergrown crystals. Crystals of ferromagnesian minerals are small, ragged, and clustered.

Huntington Lake Pluton. The Huntington Lake pluton of medium-grained mesocratic granodiorite and quartz diorite underlies about eleven square miles of the map-area.

Potash feldspar—where present in appreciable quantity—is in anhedral poikilitic crystals and is unusual in that grid twinning is lacking in it. Plagioclase is in subhedral crystals and is dominantly calcic andesine zoned to sodic andesine. Ferromagnesian minerals are in good crystals, particularly so the hornblende, which is common in relatively large euhedral prisms.

Dinkey Lake Pluton. Eight square miles of the Dinkey Lake pluton, which Krauskopf found to extend a considerable distance to the south, are present in the southeastern part of the map area. Within the map area, the northern part of the pluton is alaskite, the southern part, granite.

The alaskite is medium- to coarse-grained and contains only trifling quantities of minerals other than quartz and alkali feldspars. Quartz is smoky and is in large sprawling anhedral crystals. Potash feldspar shows the coarsest grid twinning and perthite of any of the granitic rocks and is in subhedral to anhedral crystals, partly intergrown with albite. Albite, with some sodic oligoclase, is present partly in small subhedral crystals, partly in anhedral crystals of all sizes in intergrowths with each other and with potash feldspar.

The granite is similar. It contains up to several per cent of ragged grains of biotite and muscovite. Most of the plagioclase is sodic oligoclase zoned to albite and occurs in subhedral crystals, but additional albite has effected some replacement of both microcline and oligoclase. Quartz is of a lighter smoky color than that of the alaskite.

A little anhedral magnetite is present in both rock types. Red garnet is also present in the alaskite whereas sphene is present in rare grains in the granite.

Pegmatite nodules, common in parts of the alaskite, are discussed elsewhere.

Coyote Creek and Rancheria Creek Plutons. The rocks of the $1\frac{1}{2}$ square mile Coyote Creek pluton and the eighth of a square mile Rancheria Creek pluton are similar to the alaskite of the Dinkey Lake pluton except that they are slightly finer-grained.

Sheepthief Creek Pluton. The Sheepthief Creek pluton occupies 3 square miles of the southwestern part of the area, but only part of the pluton is within the map area. The pluton is medium- to coarse-grained leucocratic granite, with somewhat more biotite than hornblende. Both these minerals occur in ragged crystals. Plagioclase present in most specimens is calcic oligoclase in subhedral to euhedral zoned crystals.

Tamarack Creek Pluton. Eight square miles of the Tamarack Creek pluton extends along the southern part of the mapped area. Kranskopf found this pluton to extend long distances south and southwest of this area. The rocks of this pluton are medium-grained, and vary from quartz monzonite in the southeast to quartz diorite in the northwest.

Red Lake Pluton. The Red Lake pluton is relatively fine-grained and light-colored quartz monzonite underlying about 18 square miles in the south-central part of the area.

Most of the thin sections examined of rocks from this pluton were of quartz monzonite, but several each of granodiorite and granite were found. The disposition of these latter types is random within the limits of the sampling, and the rock types could not be separated by reasonable isopleths.

Although grains of other minerals average only a millimeter or two in size, potash feldspars commonly occur in anhedral poikilitic crystals with diameters up to a centimeter or more. Plagioclase, which is mostly sodic andesine rimmed by oligoclase, occurs in small, subhedral, somewhat embayed crystals.

Biotite in small ragged distinct grains is the characteristic accessory mineral. Ragged hornblende crystals are present in trifling quantity in most of the pluton. Muscovite is common in the several areas in which the rock becomes aplitic.

The grain size of the rocks of the pluton generally increases eastward.

Rodeo Meadow Pluton. The Rodeo Meadow pluton of quartz monzonite underlies about 3 square miles of the southeastern part of the area. The rocks of this pluton are quite similar to those of the eastern part of the Red

Lake pluton; like them, the rocks are relatively fine-grained and light-colored.

Plagioclase in the rocks of this pluton is dominantly calcic oligoclase, and is thus somewhat more sodic than the plagioclase of the Red Lake pluton.

Helms Creek Pluton. The dikelike Helms Creek pluton of granodiorite underlies only about 1 square mile of the southeastern part of the map area and is probably the youngest of the granitic rocks present in the area. Its plagioclase is relatively little-zoned sodic andesine. Biotite and hornblende, present in roughly equal proportions, give the rock a mesocratic appearance. Abundant square-tabular phenocrysts of potash feldspar are present in the rock. Flow structures are so well-developed in this pluton as to give the rock an almost gneissose foliation parallel to its contacts.

Leucogabbro. The leucogabbro near Nellie Lake occupies an area of only a dozen or so acres.

The rock is medium-grained and mesocratic. Plagioclase crystals, sodic bytownite zoned to sodic labradorite, occur small to large, anhedral to subhedral, and are white to medium gray or greenish gray in hand specimen. Plagioclase feldspar makes up nearly three-quarters of the rock. Potash feldspar (1 percent of the rock) and quartz occur in small anhedral grains. Euhedral to subhedral hornblende occurs in separate crystals and as reaction rims on stubby prisms of augite. The C-axes of augite cores and hornblende rims are parallel. Magnetite and sphene together make up 2 or 3 percent of the rock, and thus are far more abundant in this rock than in any of the other granitic rocks.

Joints

The only consistent joint pattern found was a general northeast to north-northeast trend of the most prominent vertical or near-vertical joints of most of the eastern half of the area. No consistent trend could be shown for the western part of the area. The northeast joints cross through a number of plutons and are thus independent of pluton contacts.

Measurements of attitudes of joints, although extensively made, proved much inferior to inspection of aerial photographs for the determination of important joints.

Joints are most regular and widely spaced in the coarse-grained rocks. The northeast joints in the coarse granodiorite of the Mt. Givens pluton in the vicinity of Mono Hot Springs are exceptionally well developed and were subjected to selective quarrying by the large glacier in the valley of the South Fork of the San Joaquin River so that a large area now has a striking corrugated appearance.

Exfoliation joints are excellently developed in the alaskites.

The relatively fine-grained rock of the Red Lake pluton characteristically is jointed closely by gently dipping joints that give exposures a slabby appearance.

Aplite and pegmatite dikes are uncommon in most of the Huntington Lake area and lack consistent orientation in most places in which they do appear. Locally, dikes are consistently within joints of one system. Thus there are several thick horizontal aplites at and near Mt. Givens, some more north of Nellie Lake, many gently dipping pegmatite dikes in the Tamarack Creek pluton southwest of Huntington Lake, and many small vertical aplites with an east-northeast trend in the granodiorite of the Huntington Lake pluton.

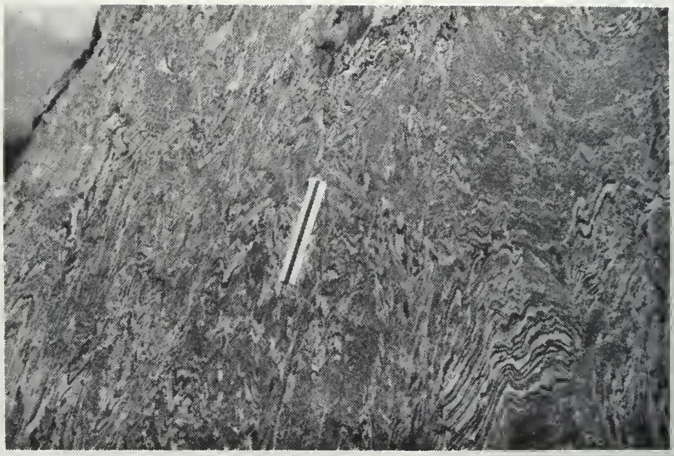


FIGURE 4. Contorted pyroxene hornfels in septum near Idaho Lake. Scale is 6 inches long.

Flow Structures

Observed attitudes of primary flow structures in the granitic rocks are plotted on the geologic map. The flow structures are in general parallel to contacts where near those contacts, and are in general best near contacts, but there are marked exceptions to these generalizations. The structures are with few exceptions steep. The quality of flow structures is best where dark minerals and inclusions are most abundant. This relation is in part apparent, due to the greater ease of recognition of the structures in the darker and inclusion-rich rocks, but is in considerable part real.

The flow structures preserve records of movements made by the magmas at a time when they were mobile but nearly solid—nearly solid, or else the orientations would not have been preserved. The flow structures demonstrate upward movement on the part of each of the plutons. In none do the flow structures form an arch or dome; this perhaps indicates that the roofs of the plutons were considerable distances above the present level of erosion. No cataclasis is associated with the flow structures, so little movement could have taken place after solidification except for movement along joint surfaces.

Aplite and Pegmatite

Aplite dikes are present in granitic rocks of many parts of the Huntington Lake area. Most of these dikes are a few inches wide and a few tens of yards long, but the flat-lying dikes at Mt. Givens have thicknesses of more than 50 feet, and the large irregular aplite mass near the southwest end of Huntington Lake has a length of a mile and a width of several hundred yards. Most of the aplites are xenomorphic granular fine-grained rocks composed of potash feldspar, sodic plagioclase, and quartz, with biotite or muscovite present in minor quantity. Some of the larger masses, particularly the one just mentioned, are more nearly hypautomorphic granular in texture, contain several percent of biotite, and are similar to the fine-grained leucocratic quartz monzonite of the Red Lake pluton.

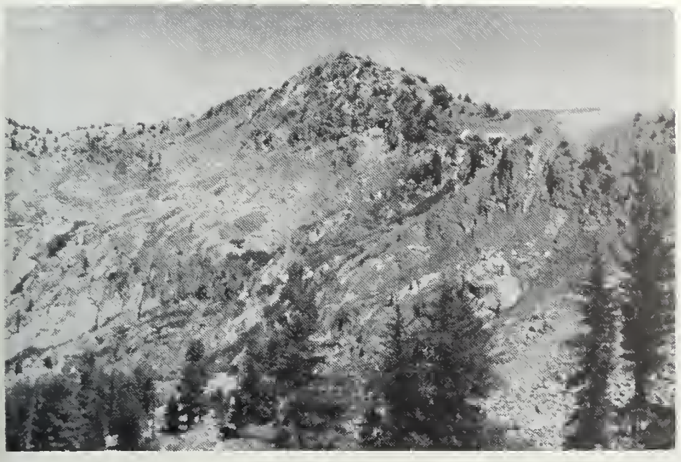


Figure 5. Kaiser Peak from the northwest. Metamorphic rocks, mostly quartzites, form vertical bands in right half of picture.

Aplites are more abundant than are pegmatites, but even the aplites are common only locally.

Small simple pegmatite dikes occur in many parts of the area but are common only locally. Elliptical masses of pegmatite, often with miarolitic cavities, are abundant in some of the alaskitic rocks.

Replacement pegmatite dikes are common only in the metamorphic rocks. In the granitic rocks, most of the pegmatites are sheetlike and follow joints, although a few are irregularly branching and lensing. Most pegmatites more than a few inches wide in the granitic rocks are banded more or less concentrically, with aplitic and pegmatitic bands of varying grain size and mineral proportions. Perthite—pale orange or lavender colored—is the most abundant mineral, with gray quartz and white sodic plagioclase present in varying amounts and varying intergrowths. Minor accessory minerals are magnetite and bladed biotite.

The most interesting pegmatites are those of the alaskites, and particularly those of the Dinkey Lake pluton east of Dinkey Lake and south of Black Peak. Whereas other parts of the alaskite contain pegmatite dikes, this part of the alaskite contains pegmatite amounting to perhaps 1 percent of the rock in the form of elliptical masses varying in diameter from a few inches to a few tens of feet. No dikes are present here, only the lenticular masses. The larger masses are roughly zoned. Grain size of the alaskite increases gradually toward the lenses—sharp contacts are lacking—until the rock becomes pegmatitic. The proportion of quartz to feldspar (large crystals of perthite, small crystals of albite) increases inward so that the innermost part of the pegmatite commonly consists of euhedral crystals of smoky alpha quartz projecting into a cavity. In some of the pegmatite lenses, the quartz is in part white or clear; this quartz is commonly rimmed by the smoky variety, which is also the quartz type of the alaskite itself. The complete transition may take place over a distance of 10 feet and the pegmatite may contain quartz and feldspar crystals several feet long; or the complete transition may be represented in a single hand specimen in which no contact can be drawn between "igneous" alaskite and "aqueous" quartz.

Age of the Granitic Rocks

The granitic rocks are definitely younger than the folding and dynamothermal metamorphism of the metamorphic rocks. They truncate sharply the folds of the metamorphic rocks, show no metamorphism beyond trifling retrograde alteration, and show no cataclasis.

The youngest metamorphic rocks of the northern Sierra are those of the Mariposa formation of middle Upper Jurassic age; the oldest rocks resting on the granitics and metamorphics are those of the Upper Cretaceous Chico formation. The Oregon rocks equivalent to the Mariposa formation are metamorphosed and are overlain by non-metamorphosed uppermost Jurassic rocks (Hinds 1934). From this evidence, all of the Sierran granitic rocks have been commonly considered of late Upper Jurassic age.

Larsen et al. (1954), who have been investigating the age of California granitic rocks, state that "Seven age determinations on rocks from the Sierra Nevada batholith give an average age of 100 million years." An age of 100 million years is considered middle Cretaceous.

All of the Sierran granitic rocks are probably products of the same orogenic cycle—the Nevadan orogeny. The granitic rocks of Baja California must similarly belong to the same cycle, yet there the granitic rocks are at least in part of early Upper Cretaceous age (Woodford 1940; Beal 1948). In British Columbia, similar rocks were formed during the Jurassic, Cretaceous, and even the early Tertiary (Geological Survey of Canada 1947, pp. 242-245). Such variance in dating of Nevadan granitics makes it inadvisable to claim that all of the Sierran plutons are of so precise an age as late Upper Jurassic.

In the Sierra, most plutons were intruded after their predecessors were solid or nearly so. Within even limited areas (e.g., the Yosemite region: Calkins 1930), plutons formed in groups in which all members of one group preceded those of the next. These facts, with others, suggest that the formation of the granitic rocks occupied a long time span; dating more precise than "Jurassic and Cretaceous" seems unjustified.

Weathering

Most granitic rocks of the Huntington Lake area weather to rounded boulders and to coarse sand which are of similar appearance for nearly all rock types. Boulders are deeply weathered and show little spalling of weathered material, so that in non-glaciated areas it is often impossible to obtain fresh specimens. Phenocrysts of potash feldspar from the porphyritic rocks commonly weather out and retain their shape in the residual sand. Color of the weathered rocks is white, gray, or buff.

The relatively fine-grained Red Lake and Rodeo Meadow quartz monzonites weather differently. Boulders of these rocks spall apart so readily that fresh rock is exposed at the surface over much of the boulders.

Alaskite is the rock type most resistant to weathering.

Sequence of Intrusion

In some of the glaciated parts of the Huntington Lake area, contacts of the granitic rocks with each other and with metamorphic and hybrid rocks are excellently exposed in fresh bare rock. In most of the area, however, contacts can be mapped by conventional methods but actually can be observed only rarely.

Contacts between granitic rocks are extremely simple in many places; rocks of two plutons meet and grade into each other in a zone not more than a few inches wide, or simply interlock crystals. In many cases there is no evidence to be seen of any action, chemical or physical, exerted by one pluton on the other. Yet large volumes of rock have been displaced or incorporated by later plutons. These simplest contacts are to the writer the most puzzling of all of the types of contacts. Other contacts are gradational, or swirled, or have involved obvious displacement of one of the plutons.

Clear intrusive relations between rocks of adjoining plutons were found in few places. This is due in part to the poor quality of exposure throughout much of the area but is also a reflection of the ambiguity of contact relations even where exposures are excellent. Age relations recognized in the contacts permit these deductions: (1) The Kaiser Peak pluton is older than the Mt. Givens pluton, which is in turn older than the Coyote Creek, Rodeo Meadow, and Red Lake plutons; (2) The Tamarack Creek pluton is older than the Red Lake and Dinkey Lake plutons; (3) The Red Lake pluton is older than the Dinkey Lake pluton, and both are older than the Helms Creek pluton.

The presence of quartz lacking mosaic extinction in the rocks of the southeastern part of the Huntington Lake area suggests that the rocks containing it formed later than did the rocks with mosaic-extinguishing quartz. If this be true, the rocks of the Red Lake, Dinkey Lake, Rodeo Meadow, Helms Creek, Coyote Creek, and Rancheria Creek plutons, and of the southern part of the Mt. Givens pluton, postdate the rocks of the other plutons—Tamarack Creek, Sheepthief Creek, Huntington Lake, and Kaiser Peak.

The following additional age relations are suggested by the geometry of the contacts as viewed on the map: (1) Both the Kaiser Peak and Mt. Givens plutons are older than the Rancheria Creek and Red Lake plutons; (2) The Coyote Creek pluton is younger than the Red Lake pluton.

From the above information, the granitic rocks of the Huntington Lake area are believed to have been intruded in the following order, from youngest to oldest; where several plutons are named together, however, no assignment of relative age has been made within the group:

EASTERN GROUP

5. Helms Creek pluton (youngest)
4. Dinkey Lake, Rancheria Creek, and Coyote Creek plutons
3. Red Lake and Rodeo Meadow plutons
2. Mt. Givens pluton

WESTERN GROUP

1. Tamarack Creek, Huntington Lake, Sheepthief Creek, and Kaiser Creek plutons, and the leucogabbro near Nellie Lake

Similar rocks—the three alaskitic plutons and the quartz monzonitic Red Lake and Rodeo Meadow plutons—have been grouped together without evidence that, for example, the Rodeo Meadow pluton is older than the Coyote Creek pluton.

The suggested western and eastern groups of granitic rocks are directly comparable to the groups in the Yosemite region (Calkins, 1930). Only 35 miles separate the nearest parts of the contacts between the eastern and western groups in the Huntington Lake and Yosemite areas. The contacts in the two areas are in direct alignment in the same longitudinal part of the range. It seems reasonable that the granitic rocks of the Sierra between the Yosemite and Huntington Lake areas may be separable into two groups along this contact as projected between the two areas, and that the eastern group will contain the younger rocks. Konrad Krauskopf (personal communication) agrees that in general the younger intrusives are to the east in the area mapped by him south and southeast of the Huntington Lake area, but he considers many of the contact relations too ambiguous to permit the establishment of a complete sequence of intrusions.

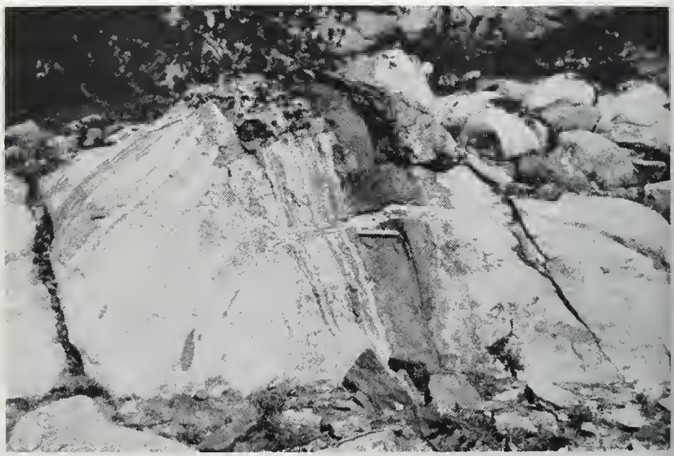


Figure 6. Contact between quartz monzonite of Mt. Givens pluton (left) and quartz monzonite of Rodeo Meadow pluton (right), separated by dark banded rock. Flow structures of Mt. Givens rocks are truncated. North of Rodeo Meadow.

The generalization is often made that granitic rocks are emplaced in order of increasing acidity, and this generalization is roughly followed in the Huntington Lake area in the eastern group of rocks where it is refuted only by the Helms Creek pluton. The age relations within the western group have not been established. The generalization can not be applied between the two groups, however, and its application is further complicated by the wide variation of composition of some of the plutons and by the similar composition of plutons of different ages.

Hybrid Rocks

Dark Inclusions. Sharply bounded dark inclusions, often given names of genetic significance such as "basic segregations" or "autoliths," are present in all of the granitic rocks of the Huntington Lake area. The inclusions are generally ellipsoidal with usual maximum dimensions of a few inches to a foot, are fine grained and have a higher proportion of dark minerals than the surrounding granitic rocks.

In some places, the inclusions are equidimensional and lack orientation. More commonly, the inclusions are flattened, or elongated, or both, and show alignment of varying completeness. In general, the better the alignment, the more elongate the inclusions. The alignment shows differential movement within the granitic magmas when they were nearly solid. The average elongation of the inclusions is about two or three to one, but many have an elongation of 10 or more to one. The inclusions are commonly triaxial and are aligned with a lineation within flow planes, but the lineation is usually difficult to determine whereas the flow planes are readily seen.

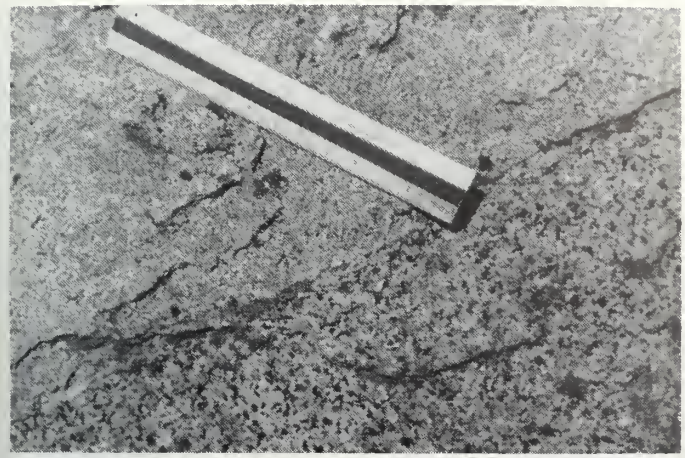


FIGURE 7. Contact between fine-grained quartz monzonite of Red Lake pluton (above) and granodiorite of Tamarack Creek pluton. Contact vertical.

The inclusions are gray to black and contrast sharply with the light-colored enclosing rocks. Grain size of the inclusions is commonly a tenth of a millimeter to a millimeter. Plagioclase makes up more than half of most inclusions. Hornblende is the most common ferromagnesian mineral, but biotite is present in nearly all inclusions and is the sole ferromagnesian mineral in many. The ratio of hornblende to biotite is generally higher than that of the enclosing rock, but decreases with the ratio in the enclosing rock. Potash feldspar is present in many inclusions, partly in small anhedral grains but mostly in large poikilitic anhedral crystals which are often extensions of large crystals of the enclosing granitic rocks. Quartz is present in small irregular grains or, less commonly, in large crystals which may be poikilitic. Large crystals of plagioclase are abundant in many inclusions, and many other inclusions have large crystals or glomeroporphyritic aggregates of the ferromagnesian minerals. Though superficially similar to each other, the inclusions vary much in grain size, proportions of minerals, and textures.

The concentration of inclusions is greatly variable. There are several inclusions per square yard of exposure in most of the northeastern part of the Mt. Givens pluton; many areas of an acre or more of alaskite lack even a single inclusion. Inclusion swarms are present in all rock types—including alaskite—and have common maximum dimensions of a few tens of feet. The abundance of dark inclusions and of dark minerals in the enclosing granitic rock vary together and appear to be related. There is no apparent relation between abundance of inclusions and locations of contacts in most of the plutons.

The writer considers the dark inclusions to be crystalloblastic, although Pabst (1928) termed them hypidiomorphic. Little order of crystallization can be determined from the textures; grains of most minerals butt against and enclose grains of all others. Sphene—the only mineral commonly well formed—is commonly present in euhedral wedges, but these contain numerous chadacrysts of the other minerals. The textures of the inclusions seem to require their crystallization in a solid or near-solid state.

Some of the minerals actually were late forming. Potash feldspar is in large poikilitic grains in most of the inclusions in which it is present. The continuity of many of the potash feldspar oikocrysts with crystals of the surrounding granitic rock and the absence of potash feldspar in many otherwise similar inclusions suggests that it is probably secondary.

There is direct evidence that at least some of the inclusions are of xenolithic origin. Some of the best of this evidence is well exposed on bare, glaciated rock near the junction of Big and Coyote Creeks at the contact between Mt. Givens and Coyote Creek plutons. Inclusions in quartz monzonite can be seen arrested in the process of splitting from larger masses of metamorphic rocks. All of the obviously metamorphic rock, with clearly metamorphic textures and structures, is near the quartz monzonite-alaskite contact, and the inclusions in this vicinity are sharply angular. This angularity decreases away from the contact until at a distance of 100 or 200 yards from it most of the inclusions are rounded to characteristic ellipsoidal shapes.

The metamorphic rocks involved here are dark, fine-grained, faintly schistose, crystalloblastic rocks composed of plagioclase (mostly unzoned andesine), biotite, hornblende, quartz, and minor potash feldspar, and are mineralogically similar to the dark inclusions found in granitic rocks of this area. The hornbende is mostly in small compact crystals and is not in meandering poikilitic crystals. Textural changes made in the metamorphic rock during hybridization to dark inclusions included the formation of porphyroblasts of plagioclase, quartz, or hornblende, and the formation of oikocrysts of potash feldspar or in some cases of quartz. These changes indicate the addition of at least soda, potash, and silica to the original metamorphic rock.

In many other areas, dark inclusions and obvious xenoliths are so closely associated that a common origin is strongly suggested. This is the case with the abundant hybrid material in the Helms Creek pluton, with the isolated swarms of inclusions of all plutons, and in parts of the large masses of hybrid rock of the southwestern part of the Kaiser Peak pluton.

The abundance of the dark inclusions is not generally related to their proximity to contacts, nor should such a relationship necessarily exist. The mapped contacts are believed to be the farthest limits reached by the plutons which incorporated and displaced the rocks they intruded. The abundance of the inclusions should be related to the position of the contacts at some time during the emplacement of the plutons—and related in a manner much more modified by movement of the granitic material. Only coincidentally should a contact at which inclusions were formed coincide with a final contact.

Petrologists proposing an autolithic origin for the dark inclusions suggest two alternatives: (1) that the inclusions are basic segregations of early formed crystals; (2) that the inclusions are of early basic intrusives belonging to the same series as the granitic rocks. The first explanation has been used by many workers but, as was emphasized by Grout (1937), an origin by segregation for inclusions such as those of the Sierra Nevada has yet to be proven or even well evidenced. The inclusions can hardly be fragments of earlier basic rocks; no early facies of the Sierran granitic complex resembles the inclusions.

The dark inclusions are indicated by their textures to have recrystallized in the solid state. They are texturally unlike either their hosts or granitic rocks. The mineralogy of the inclusions is similar to that of the enclosing rocks, but this is a necessary consequence of the equilibrium reached by the inclusions in the granitic magmas. Many of the inclusions are obviously xenoliths, and the distribution of the rest is identical wtih those that are obviously xenoliths. The writer is in agreement with Grout (1937, p. 1548) that "Any sugary-textured inclusion of an igneous intrusive should, in the abscnce of aplite and lamprophyres, be considered a recrystallized xenolith and not a segregation."

If the dark inclusions be highly altered xenoliths, they indicate that stoping operated during the emplacement of the granitic rocks. The inclusions occur throughout the granitic masses and are mostly unrelated to the present contacts, so the same processes of stoping may have operated throughout the emplacement of the magmas.

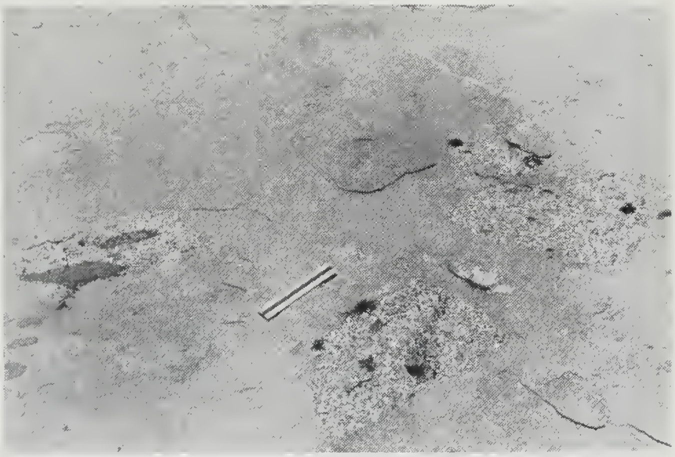


FIGURE 8. Xenoliths of granodiorite of Tamarack Creek pluton in fine-grained quartz monzonite of Red Lake pluton.

Schlieren. Schlieren—long wispy bands rich in dark minerals, especially hornblende—are common only locally in the granitic rocks of the Huntington Lake area. As are the dark inclusions, some schlieren certainly are, and most may be, of hybrid origin.

Many of the schlieren appear to be the result of the elongation by movement of the granitic host of patches in the granitic rocks rich in dark minerals. Such patches are common at all localities where large hornblende crystals are observed to have formed from metamorphic material; schlieren are common wherever such patches have been elongated by flow. However, many schlieren cannot be related definitely to metamorphic material.

Fine-Grained Rocks of Igneous Appearance. There are in many parts of the Huntington Lake area masses of fine-grained rocks, commonly mesocratic or melanocratic, which have an igneous appearance when examined in hand specimen. Such rocks are the "hybrid rocks" of the geologic map. Any one of the masses of such rocks may be fairly uniform within itself but is usually variable and markedly different than neighboring masses. These rocks have the mineralogic composition of dark quartz diorite, granodiorite, and quartz monzonite. The writer believes most of them to have resulted from the hybridization of metamorphic rocks.

In a small and completely exposed area between Big and Coyote Creeks, there are many small masses of metamorphic rocks near the quartz monzonite-alaskite contact. More common than these are ellipsoidal or irregular masses of mixed rocks, with xenoliths of all sizes of the metamorphic rocks in a patchy matrix of igneous-appearing rock. The fine-grained relatively dark "igneous" rock appears in the field to have formed by reaction between granitic and metamorphic rock, and this seems borne out by petrographic evidence. The contact between metamorphic and apparently igneous material is sharp in hand specimen or thin section. The metamorphic rock is crystalloblastic, in part faintly schistose, and consists of variable quantities of biotite, hornblende, plagioclase, quartz, minor amounts of potash feldspar, and occasional grains of diopside. The apparent igneous rock contains abundant xenocrysts of the ferromagnesian minerals and plagioclase, but quartz and potash feldspar are present mostly in much larger grains and in considerably greater abundance than in the metamorphic material. Texture of this rock is in part crystalloblastic, in part xenomorphic granular.

From this patchy matrix rock, there are all petrographic gradations to the various uniform fine-grained masses of igneous aspect farther from the contact in the quartz monzonite. Quartz and potash feldspar further increase in quantity and are present mostly in anhedral poikilitic crystals. Plagioclase acquires a sodic rim but commonly retains a calcic core, altered, embayed, and unconformably separated from the gradation to the sodic rim. The core may contain small irregular crystals of biotite and hornblende or, uncommonly, diopside. Many of the plagioclase crystals acquire a rough crystal shape, but many others are corroded, embayed, and replaced by the large poikilitic potash feldspars. Ferromagnesian minerals mostly remain in small irregular grains; in many rocks, these are clustered to make the rocks glomeroporphyritic. Particularly in these clusters, the ferromagnesian minerals may be poikilitic and contain numerous small irregular inclusions of plagioclase and quartz. Sphene in the patchy rock in contact with the metamorphic rock is commonly in extremely irregular networks enclosing the other minerals of the rock, and there are all gradations from this to the large euhedral crystals containing few inclusions in the uniform fine-grained rock of igneous appearance.

In the Big Creek-Coyote Creek area, contact relations between the fine-grained rocks and the granitic rocks are in some cases indeterminate as to relative ages of the two types. In all cases in which an age determination could be made for the mixed metamorphic and igneous masses, these masses were determined to be older than the enclosing granitics. In two of the three more or less uniform masses of igneous appearance whose relative age could be determined, the fine-grained rocks were intrusive into the quartz monzonite. Evidence for the latter relation is in xenoliths of the granitic rock near the margins of the fine-grained rock. If the writer's interpretation be correct, the end product of the process of hybridization had sufficient mobility to itself intrude the quartz monzonite.

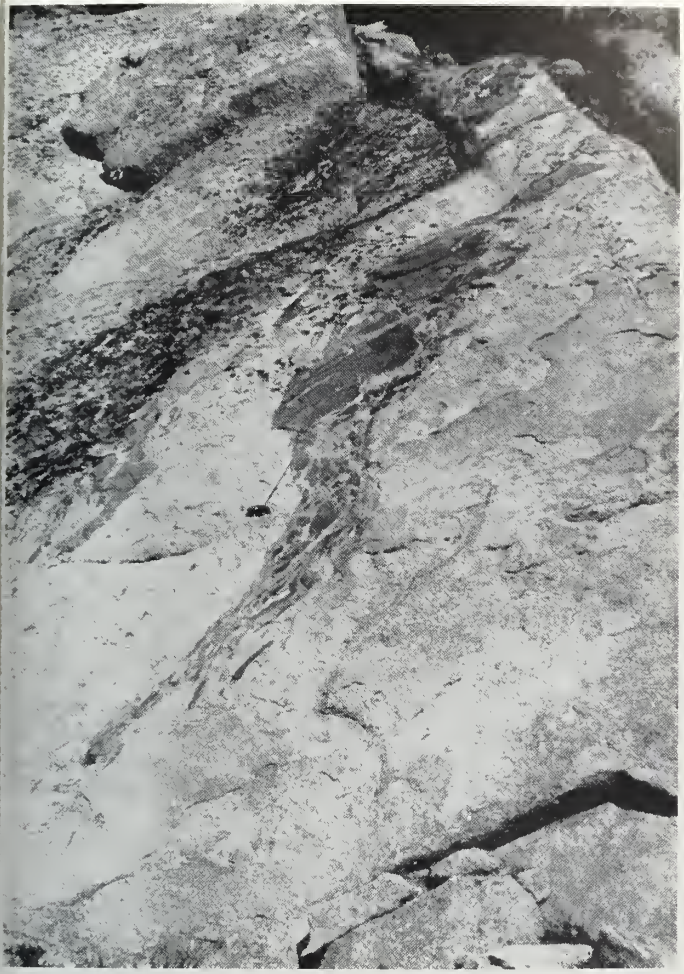


Figure 9. Dark inclusions arrested in process of break-off from metamorphic rock in Mt. Givens pluton near junction of Big and Coyote Creeks.

Similar determinations of relative age were made for the three irregular masses of dark, fine-grained rocks in the quartz monzonite of the Mt. Givens pluton north of the Coyote Creek pluton and west of the junction of Big and Coyote Creeks. One of these masses—the elongate, westernmost one—is of mixed hybrid (?) and metamorphic types and is cut by the granitic rocks; the other two are of more or less uniform hybrid (?) rocks and are intrusive into the quartz monzonite. The age relations for one of the latter are particularly clear; the quartz monzonite is xenolithically enclosed in the hybrid (?) and is cut by veins and small dikes from it.

The intrusive mass near the junction of the South and East Forks of Big Creek shown as a hybrid rock on the geologic map is a leucocratic rock of fine-medium grain size. No thin sections were studied of this rock, but it appears to be similar to some of the Red Lake quartz monzonite of the Red Lake pluton and may be related to that body rather than to the other hybrid rocks.

The sausage-shaped intrusion between Rock Meadow and Coyote Lake is somewhat finer and darker. No thin sections of this rock were examined, but the rock is similar in hand-specimen appearance to that of one of the masses of clearly hybrid rock in the Big Creek-Coyote Creek area.

The Helms Creek pluton contains many masses of metamorphic and hybrid (?) rocks similar to those of the Big Creek-Coyote Creek area.

The long mass of hybrid rocks, presumably a septum, between the eastern part of the Coyote Creek pluton and the Mt. Givens pluton is partly metamorphic rock, partly fine-grained rock of superficially igneous appearance, and partly the two types intimately mixed.

The hybrid (?) rocks of the Kaiser Peak pluton are the largest masses of such rocks in the Huntington Lake area and are chiefly fine-grained dark rocks of superficially igneous appearance. Most of these masses are variable. Several of the masses have small areas of patchy mixed types with many xenoliths of mesocratic and melanocratic metamorphic rocks and of quartzite. Many of the masses of the Kaiser Peak pluton are intimately associated with quartzite. The masses of hybrid rock which are not in direct contact with quartzite are near small masses of quartzite, so that proximity to metamorphic material is easily demonstrated for all of the hybrid (?) rocks. The poor exposures of these rocks prohibited determinations of relative ages of granitic and hybrid (?) material.

Dikes of Hybrid (?) Rocks. Dikes of probably hybrid rocks are uncommon in the Huntington Lake area. Only three (one crossing Home Camp Creek, and two at the west end of Huntington Lake) are large enough to show on the geologic map. Each of these dikes is variable within itself. Similar rocks are often termed "lamprophyres."

The contact of the northern dike (?) at Huntington Lake is well exposed in a roadcut and is interesting for its ambiguity: the dark rock contains xenoliths of granite and is cut by veins of granite.

The Home Camp Creek dike is mesocratic, glomeroporphyritic, and strikingly similar in both hand specimen and thin section appearance to one of the hybrid (?) types of the Big Creek-Coyote Creek area. If this similarity be due to a similar origin, the dike may represent an intrusion of mobilized hybrid rock. Several small dikes a foot or two wide and following joints, and themselves cut by aplites, are associated with this large dike.

The southern dike at the west end of Huntington Lake is leucocratic and appears almost aplitic in hand specimen although it contains numerous well-oriented biotite crystals. Thin section examination shows this rock to be composed of medium-sized crystals of plagioclase (sodic andesine) and quartz in a fine-grained xenomorphic to crystalloblastic matrix of plagioclase, potash feldspar, and quartz. Many of the larger plagioclase grains have an altered core containing numerous small inclusions of biotite (or chlorite) and quartz. The sodic rims of most of these larger plagioclase crystals are intergrown with the fine-grained ground mass so that these large plagioclases, although showing a rough crystal outline, are anhedral in detail.

Contacts Between Granitic and Metamorphic Rocks

The metamorphic rocks, excluding minor amounts with the hybrid rocks, of the Huntington Lake area are all either enclosed by the Kaiser Peak pluton or are between the Kaiser Peak and adjacent plutons.

Mt. Givens Pluton—Twin Lakes Marble. The contact of the marble septum at Twin Lakes with the bordering granitic rocks is exposed at only one place where the contact between marble and the Mt. Givens pluton is exposed for a distance of about 20 feet. The contact dips away from the marble at a steep to moderate angle and cuts the foliation of the metamorphic rocks.

The contact is marked by a half-inch band in the marble of brown garnet, diopside and brown garnet, or diopside and wollastonite. The contact between this band and the granitic rock is sharp. The granitic rock is texturally and mineralogically unusual, however. It is very patchy and uneven in composition and texture within 15 or 20 feet of the contact. Near the contact, it contains irregular grains of diopside and, along the garnet contacts, of chlorite. Quartz is present in exceptionally high amount and is in part in extremely irregular meandering crystals and in part in poikilitic crystals enclosing diopside and chlorite. Plagioclase—andesine—is unzoned and anhedral; most grains are complex intergrowths of several crystals and show excellently developed pericline twinning. Dark inclusions are uncommon in the granitic rock here.

Diopside is the only metamorphic mineral here incorporated into the granitic rock in its original form; xenocrysts of diopside are abundant near the contact. These xenocrysts give way to small euhedral hornblende prisms several feet from the contact. Some of these hornblende crystals contain remnants of diopside and appear to have been formed by reaction with it; the other hornblendes are similar and probably had a similar origin.

Diopside was certainly assimilated and so also must have been the associated garnet and wollastonite, but neither of the latter cross the contact in their original form. The plagioclase of the granitic rock is uniform in composition. Although the anorthite content of the plagioclase crystals is the same as that of the central part of the zoned plagioclase crystals elsewhere in this part of the Mt. Givens pluton, the crystals here are more calcic than the average as they lack the sodic rim present elsewhere. This local enrichment of lime is probably due to the addition of lime to the magma from the wollastonite and perhaps also of lime and alumina from the garnet.

Garnet was not incorporated as such into the granitic material. It seems likely that the chlorite, abundant in the granitic rock near the contact with the garnet, was derived from it, but no chloritic border or other direct evidence of this possible reaction was observed.

The reactions indicated by these mineral changes suggest that marble was completely assimilated by granodiorite. Large quantities of material—especially silica—were added to the marble, and the assimilation was accomplished through intermediate calcareous silicates. The high quartz content of the granitic rock near the contact seems to show that silica was added to the granitic rock as well as to the marble.

Idaho Lake Septum. The contacts of the Mt. Givens and Kaiser Peak plutons with the thin septum of schist and hornfels near Idaho Lake are completely exposed on fresh glaciated rock surfaces of the Idaho Lake cirque. The septum is composed of pyroxene hornfels and hornblende-biotite schist, with minor quantities of impure quartzite.

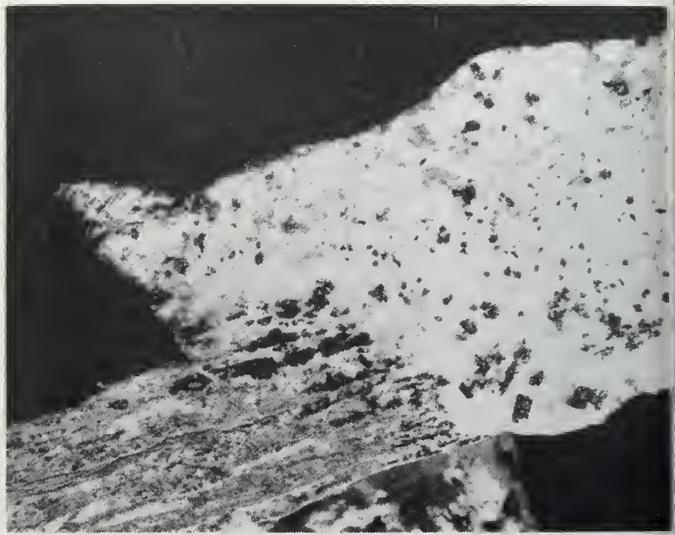


FIGURE 10. Contact between pyroxene hornfels (banded) and granodiorite of Mt. Givens pluton at septum near Idaho Lake. Porphyroblastic and poikiloblastic hornblende crystals are present in the hornfels, and similar hornblendes are in the granitic rocks. Natural size.

The contacts of the two plutons with the septum are markedly different. The Mt. Givens magma incorporated the pyroxene hornfels by assimilation: dissolved quartz and feldspar from it, and reacted with the pyroxene to form hornblende. The Kaiser Peak pluton, by contrast, is interpreted to have incorporated the schist in preference to the pyroxene hornfels, and to have done so by a quite different process of assimilation.

Near the contact with the Mt. Givens pluton, the pyroxene of the hornfels reacted to produce large poikiloblastic hornblende crystals. All stages of this reaction are excellently illustrated in thin section, from anhedral hornblendes that have replaced only a few tiny pyroxene crystals to large euhedral hornblendes each resulting from the replacement of several hundred pyroxene grains. The outlines of the oikocrysts are anhedral in the grains farthest from the contact but they become progressively better until at the contact most of the hornblende crystals are euhedral although commonly sievelike in texture. Feldspars and quartz of the hornfels were dissolved rather than altered to new minerals; this and the pyroxene-hornblende reaction give excellent examples of Bowen's reaction principle (Bowen, 1928). The solution of the quartzo-feldspathic part of the hornfels freed the hornblendes so that their orientation is lost at the contact between granitic and metamorphic rocks. The hornblendes of the granitic rock near the contact are poikilitic and in all respects similar to those formed poikiloblastically in the hornfels, but the chadacrysts decrease in abundance away from the contact so that the hornblende a few inches or a few feet from the contact is commonly relatively clear of inclusions. The hornblendes so formed, poikiloblastic replacements of pyroxene later cleared of chadacrysts, appear identical with most of the hornblendes throughout the Mt. Givens pluton. Many of those hornblendes probably had a similar origin as xenocrysts derived by reaction with pyroxene of metamorphic rocks and it is possible that most of them had such an origin in reaction rather than in crystallization from a liquid. Quartz, plagioclase and potash feldspar were completely dissolved from the hornfels, and their subsequent recrystallization would have been genuinely gneous.

Much of the pyroxene hornfels was deeply and irreguarly embayed by pegmatite and leucogranodiorite, and much of the septum is bounded by a thin zone of leucogranodiorite rather than by the normal granodiorite. The pegmatite and leucogranodiorite grade smoothly nto the normal granodiorite across a distance of a few feet or yards. Most of the pegmatitic and leucogranodioritic bodies in the hornfels are of chiefly replacement origin, although straight and sharply bounded dilation dikes a few feet thick are common.

Evidence for the replacement character of the pegmatites is given by the geometry of their contacts and the orientation of inclusions within them. Contacts are commonly complexly irregular, anastomising, with embayments of all shapes and sizes. The masses contain abundant islands (as viewed in two dimensions) of metamorphic rocks, in most of which the structures show no offset or change in orientation from structures in the walls. Incorporation of wall rock components into the granitics is shown clearly by the evidence for assimilation, almost continuous along the contact, of the type described above. On the other hand, the pegmatite and eucogranodiorite show conclusive evidence of fluidity. Many inclusions have random orientations, clearly moved from their initial positions. Hornblende, formed by assimilation reactions from metamorphic pyroxene, s excellently oriented in the hornfels with long axes in the plane of foliation, yet is random in the granitic rocks even a fraction of an inch from the contact at which it was liberated by solution of the quartzo-feldspathic components. No ghost structures, faint relics of metamorphic fabric, are present in most of the pegmatites.

This evidence for fluidity disproves the possible explanation that the emplacement of the pegmatites was by a process in which solid pegmatite expanded by replacement of hornfels. Rather, it is pictured that a granitic liquid, penetrating along fractures, assimilated the wall rocks, exchanging material by direct circulation with the main magma mass. This replacement was in many places incomplete and left a skeleton of wall rock which now appears as islands.

If it is assumed that all of the hornblende in the Mt. Givens pluton in the vicinity of the Idaho Lake septum ormed from pyroxene hornfels, an estimate can be made of the ratio of introduced granitic material to hat of assimilated hornfels in the granodiorite now present. Pyroxene constitutes an average of perhaps 5 percent of the hornfels, hornblende 5 percent of the granodiorite, so the ratio of introduced to total incorpoated material would be on the order of four to one.

Much of the granodiorite near the septum is patchy. n many places, partially digested xenoliths of pyroxene ornfels are surrounded by hornblende-rich areas, and here are all stages intermediate between xenoliths and aint patchy areas in the granitic rock.

Stoping, locally active by the Mt. Givens pluton along his septum, is shown in places by the gradation as much s 50 feet wide between hornfels penetrated by a few ikes and granodiorite with abundant xenoliths. The ranodiorite is particularly patchy along the part of the ontact where stoping accompanied assimilation.

The contact relations of the Kaiser Peak pluton with the septum are strikingly different. Rock of normal granitic appearance is not present within several hundred feet of the septum; there is a gradual change from fine-grained xenomorphic quartz monzonite with relic metamorphic minerals and textures at the contact to coarse quartz monzonite of normal appearance. The fine-grained rocks have a superficially aplitic appearance. The rocks are leucocratic, xenomorphic and porphyroblastic. Many of the porphyroblasts contain numerous minute inclusions of the other minerals. Quartz porphyroblasts are in egg-shaped clusters, and feldspar porphyroblasts are in grains with a rough crystal shape. The aplitic rocks grade into coarse normal quartz monzonite by a gradual increase in abundance of coarse grains.

The contacts observed between aplitic quartz monzonite and biotite-hornblende schist vary from sharp (mostly) to gradational over a zone less than a foot wide, with the gradation represented by wisps of schist which maintain their structural orientation across the contact. In the schist within a fraction of an inch of the contact, the place of much of the metamorphic hornblende is taken by irregular poikiloblastic network crystals of biotite up to several millimeters long and discontinuous in section. Many micro-xenoliths of schist are present in the aplitic quartz monzonite.

Some of the aplitic rock is foliated. The planar orientation is due to long oikocrysts of hornblende and biotite similar to those of the metamorphic rocks. The orientation of these grains is parallel to the foliation of the nearby metamorphic rocks.

The great change in composition across the generally sharp contact between schist and quartz monzonite shows that a large proportion of the granitic material was introduced and suggests that the quartz monzonite was intrusive. However, continuation of metamorphic structures a few inches into the quartz monzonite in many places suggests a replacement origin for the quartz monzonite, a possibility supported by the considerable area of foliated ghost-structured quartz monzonite. The poikilitic hornblende and biotite in the quartz monzonite within several hundred feet of the contact apparently were derived from the metamorphic rocks. Textures in the granitic rocks near the contact are fine-grained and very unusual, and may be interpreted as crystalloblastic. The writer interprets the somewhat conflicting evidence to indicate large-scale assimilation, the incorporation of metamorphic material into a pluton, with subordinate granitization, the formation of granitic rock by replacement of metamorphic rock.

The contact between the aplitic quartz monzonite and the septum is complexly irregular in both plan and section. Dips vary from steep to gentle, both under and away from the septum. The irregularity and lack of shearing of this contact (as of that with the Mt. Givens pluton on the other side of the septum) precludes the possibility of emplacement of the granitic mass primarily by forceful injection, and instead indicates that the quartz monzonite replaced the schist; this replacement was probably both physical and chemical.

Quartzite Enclosed in the Kaiser Peak Pluton. Numerous quartzite bodies ranging in size from small xenoliths to square-mile masses are enclosed by the Kaiser

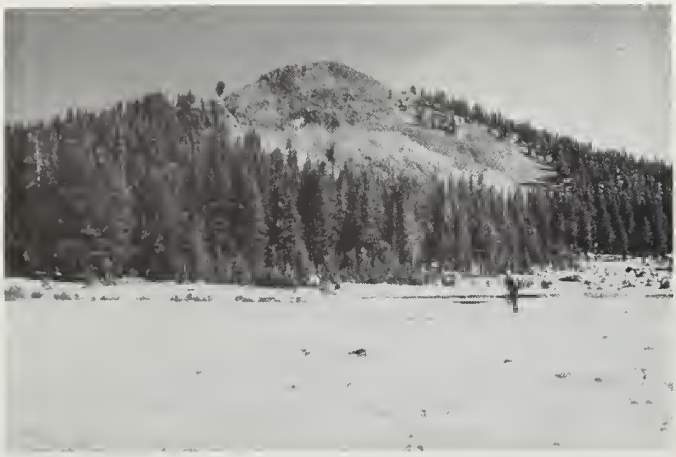


FIGURE 11. Black Peak is a plug of hornblende andesite. Contact with granitic rock is approximately the position of tree line.

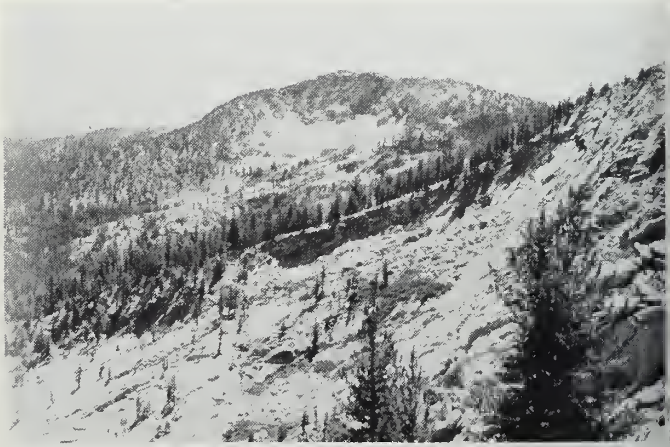


FIGURE 12. Mt. Givens from west, showing small cirques. Rocks are granitic.

Peak pluton, but exposures of contacts were seen only in several places in cirques.

The very pure quartzites—the bulk of the quartzites—show only a slight coarsening toward the granitic contacts and the formation of a few coarse lenses. No changes were recognized in the granitic rocks in contact with these pure quartzites.

The granitic rocks in contact with the impure quartzites which contain considerable amounts of feldspar and biotite are much different. Many masses of such quartzite are wholly or partly surrounded by rock of aplitic appearance similar to that at the Idaho Lake septum. Quartz in this aplitic rock type is in egg-shaped aggregates. Potash feldspar is present in some localities as large euhedral crystals that appear porphyroblastic in hand specimen and that seem identical to the phenocrysts which are common in the normal granitic rock into which the fine-grained rock grades.

Gneissose Rocks of the Kaiser Peak Pluton. Perhaps a quarter of the north-central and northeastern part of the Kaiser Peak pluton consists of rocks of gneissose appearance and the previously described aplitic rocks. The types are closely associated, and the former is the more abundant. Gradations between the two types and between them and the normal coarse granitic rocks may be seen. Similar rocks are not present in any of the other plutons.

The gneissose rocks are highly variable. Some appear in hand specimen to be rudely foliated granitic rock. In others the bands of dark minerals divide the leucocratic minerals into small lenses. Massive granitic bands alternate with fine-grained generally darker bands in many rocks. Many of the rocks contain large subhedral to euhedral crystals of potash feldspar.

The dominant texture of the rocks is interpreted to be crystalloblastic. Schistose bands are of clustered fine-grained biotite and hornblende with the former generally predominant. Quartz and feldspar are, in part, in small crystalloblastic grains, in part in large porphyroblastic grains. Quartz is generally free of inclusions, and the larger grains are mostly in egg-shaped aggregates. Large feldspar crystals commonly contain many inclusions of the other minerals. The larger the feldspar grains, the better their crystal shapes tend to be; potash feldspar crystals over an inch long are commonly euhedral. Most of the large potash feldspar crystals contain inclusions of plagioclase and quartz illustrating all degrees of their replacement. Some of the inclusions are in aligned trains but most are random. Large crystals of quartz and feldspar are intergrown about their margins with the fine-granular material.

The appearance of some of the rocks, particularly the augenoid ones, suggests that they have been sheared Microscopic examination neither conclusively proves no disproves this, but does show that if the rocks were sheared, the shearing was succeeded by some recrystallization. Some of the larger grains of these possibly sheared rocks are surrounded in part by angular grain mostly of the same mineral. Foliation bends around the large grains in most of the gneissose rocks, augenoid and others.

Whether or not shearing acted on some of these gneissose rocks late in their development, it does not appear to have affected most of them. The fragmented grains observed in several specimens are lacking in mos specimens. The unsheared and the possibly sheared rock occur together in the same small masses.

The gneissose and aplitic rocks occur together in numerous large and small patches in the area from 2 mile west to 3 miles east of Kaiser Peak. Nearly all of the schist, ferromagnesian hornfels, and impure quartzite of the Huntington Lake area is within or bounded by the portion of the Kaiser Peak pluton that contain these gneissose rocks. The aplitic rocks form a continuou zone around the impure quartzite mass 2 miles west o Kaiser Peak, and with a minor proportion of the gneissose rocks form a broad border along the septum o metamorphic rocks near Idaho Lake. Small patches o these rocks are present in great abundance in the vicinity of Kaiser Peak—an area which also contains numerou small masses of schist, hornfels, and impure quartzite

Only a few completely exposed contacts with thes metamorphic rocks were seen, and these contacts wer against either pseudo-aplitic or patchy granitic rocks No contacts between metamorphic and gneissose rock were seen.

The writer believes these gneissose rocks to be partially granitized metasediments. Contacts of the gneissose and granitic rocks are sharp in some places, gradational in others. Some of the gneissose masses are elongate bu

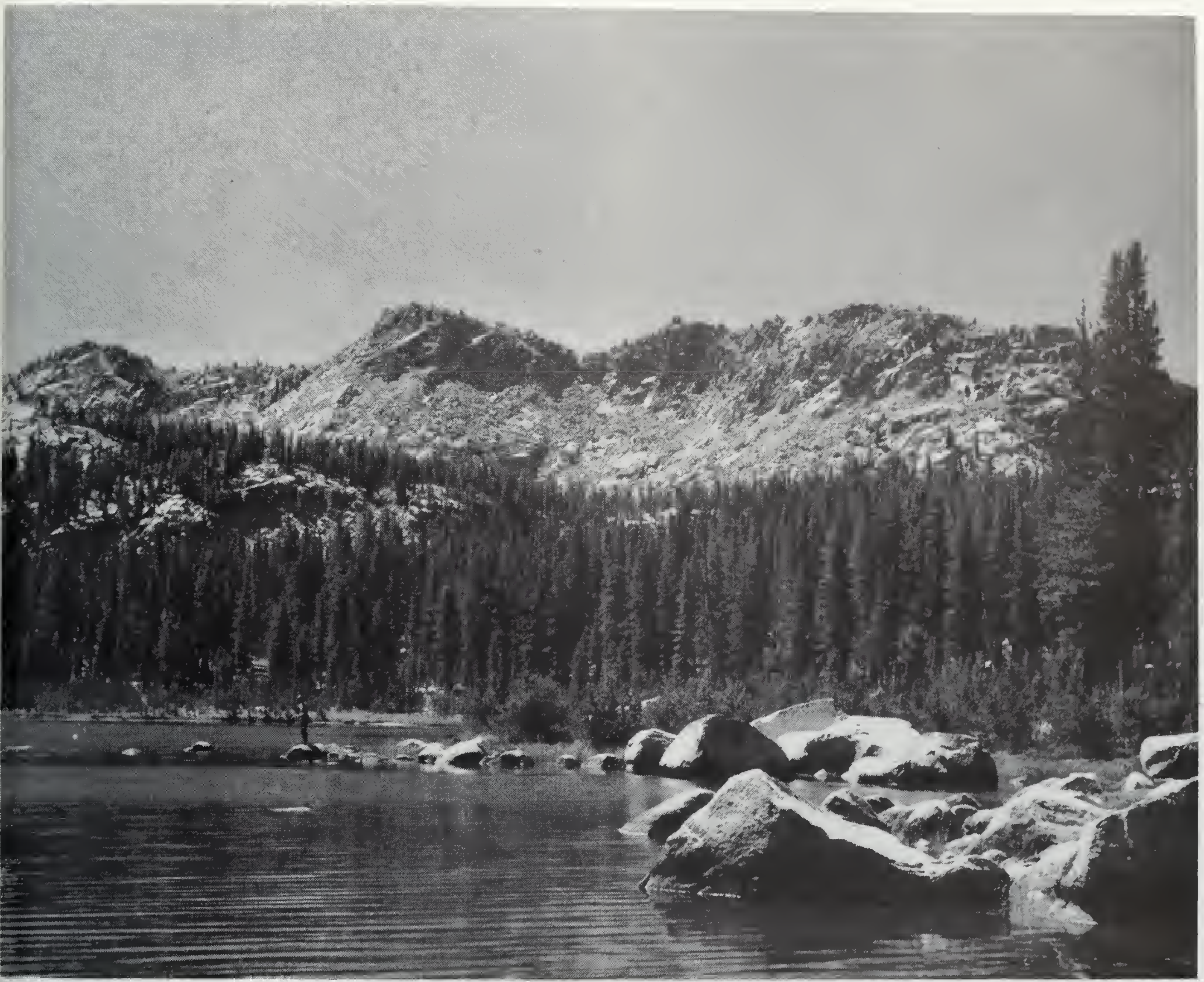


Figure 13. Dinkey Lake occupies a depression in ground moraine. Cirqued crest in background (south) is of granite.

many others are equidimensional, with foliation butting against massive granitic rock. Foliation in some of the masses is very irregular. Although local textures of the gneissose rocks might be interpreted as evidence of cataclasis, even those rocks which appear possibly sheared are crystalloblastic in large part. No evidence of possible shearing was recognized outside of the gneissose masses. The fine-grained bands and masses within the gneissose rocks appear to be highly altered metamorphic rock.

Modes of Emplacement

The granitic rocks of the Sierra Nevada form an exposed mass 300 miles long and as much as 70 miles wide, yet this great body now occupies a space that was once filled by metamorphic rocks. How were the granites emplaced?

The granites are intrusive. Most of the metamorphic rocks in contact with them show the effects of strong contact metamorphism; evidently the granites brought heat with them as they ascended. Contacts are sharp, and gradation from granite to country rock commonly takes place in less than an inch. The granites were intruded in hundreds of separate plutons, some a few acres in extent and some covering several hundred square miles. The intrusive material was mobile. The uniformity of the granitic rocks over wide areas, and the gradual nature of the variations indicate that large volumes of the material could be mixed and homogenized. Some of the intrusive material must have been wholly liquid (as in the alaskites), whereas some was only partly liquid.

The granites intruded and metamorphosed by contact a country rock which had already undergone moderate regional metamorphism, the emplacement occurring after deformation and regional metamorphism of the country rock were essentially complete. Structures in the metamorphic rocks are cut across sharply by the granites, and straight dilation dikes from the granites transect contorted metamorphic rocks. It is possible, however, that some of the deformation of the country rock was the result of forces of intrusion acting prior to the establishment of the final contacts. Early plutons intruded the metamorphic rocks; later plutons intruded the early plutons.

The intrusive granites moved generally upward, as shown by their flow structures. At levels now exposed to erosion, the great bulk of the granite, whatever its origin, was brought up from lower levels. Most of the space now occupied by the granite must have been gained by physical displacement, either upward, downward or outward, of older granitic or metamorphic rocks. Precisely how this was achieved is a complex and puzzling problem, evidence for which is contradictory.

No single process of intrusion can account satisfactorily for the emplacement of the Sierran plutons; the emplacement resulted from a complex and variable combination of processes. The following processes should be considered:

A. Chemical processes
  1. Assimilation
  2. Granitization

B. Physical processes
  1. Stoping
  2. Cauldron subsidence
  3. Forceful intrusion
  4. Permissive intrusion, tectonically controlled

Assimilation. The incorporation of material from the wall rocks into the pluton magmas operated extensively along some contacts. The assimilation of pyroxene hornfels near Idaho Lake resulted in the formation of hornblende from pyroxene by contact reaction; this hornblende was incorporated bodily into granodiorite, while felsic minerals from the hornfels were dissolved and incorporated into the magma in liquid form.

The contact between the Mt. Givens pluton and pyroxene hornfels near Idaho Lake shows abundant features of small-scale replacement of metamorphic rock by granitic material. Goodspeed (1940, 1948), working with strikingly similar features near Cornucopia, Oregon, has concluded that entire plutons having such contacts are of replacement origin. Most of the features described by Goodspeed at Cornucopia can be recognized at Idaho Lake. The metamorphic rocks in both areas, however, are hornfelses, and show by their textures and mineralogy that they were formed when a steep temperature gradient existed from granitic rocks into wall rocks; the plutons in both areas must have been intrusive to have produced such gradients. The granitics involved have compositions grossly different than do the metamorphics. The convincing evidence of fluidity of the Mt. Givens pluton also rules out the possibility of formation by solid granitization.

The writer regards replacement features of the type at Idaho Lake to be the result of marginal assimilation by intrusive plutons. Although such assimilation may have acted throughout the period of intrusion, adding much material to the plutons and aiding in producing space for the intrusives, the process can not have been the major means of their emplacement.

Granitization. In the Huntington Lake area, only the northern part of the Kaiser Peak pluton shows features which the writer regards as possible evidence for formation of granite in part by granitization. Even here, most of the granite was intrusive.

Granitization has probably operated on a huge scale in many areas, as in parts of the Canadian shields and perhaps in parts of the northern Cordillera, but the structure and petrology of such areas are far different from those of the Sierra. Gneisses and migmatites, for example, are virtually lacking in the Sierra, yet form vast terranes in regions of probable large-scale granitization. Perhaps such areas of granitization are exposed by erosion to levels lower than those cut into the intrusive plutons of the Sierra. Perhaps regional granitization on the one hand and the intrusion of batholithic complexes on the other represent different levels of a continuous process, wherein ultrametamorphism forms mobile granitic magmas which in turn intrude upward.

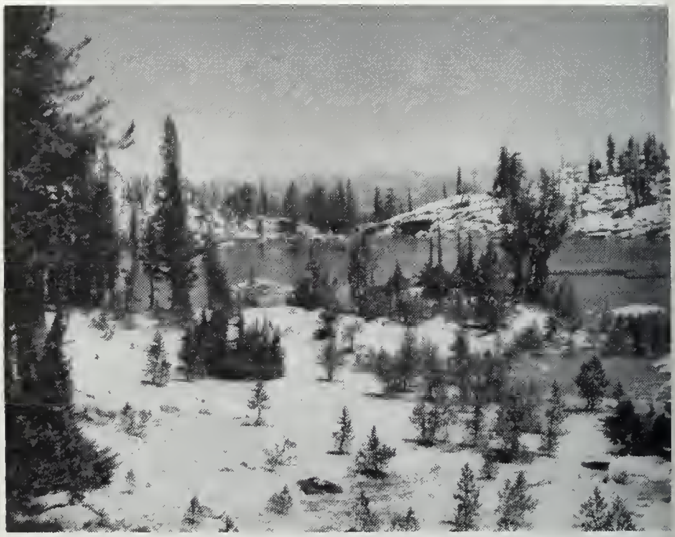


FIGURE 14. Island Lake, near Dinkey Lake, occupies a shallow glacial basin in granite.

Stoping. Stoping operated, but to a degree that is only conjectural. Only the stable hybridized xenoliths (particularly the dark inclusions, if these are xenoliths) are common, so most stoped fragments must have been completely assimilated.

The stoping theory gives an attractive explanation for the irregularity of contacts where chemical replacement is not indicated, and particularly for contacts where several plutons are in direct contact yet show no evidence of chemical interaction. But if stoping was a dominant process in the emplacement of plutons, it ceased to be important in the last stages of intrusion. When crystallization had progressed far enough to maintain orientations of minerals and inclusions, stoped blocks would not have sunk; as blocks are present at few places along the contacts, late-stage stoping must have been minor. The means of disposal of stoped blocks, if ever present in abundance, is unexplained.

Cauldron Subsidence. An explanation in terms of cauldron subsidence—stoping on a huge scale—could account for the emplacement of some of the plutons, particularly the smaller ones which are intrusive entirely into other plutons. However, no evidence for such emplacement has been recognized in the Sierra except that the geometry of some contacts might favor it. The theory of cauldron subsidence also leaves unexplained the fate of sunken blocks.

Forceful Intrusion. The pushing upward and aside of older rocks by forceful intrusion is considered by

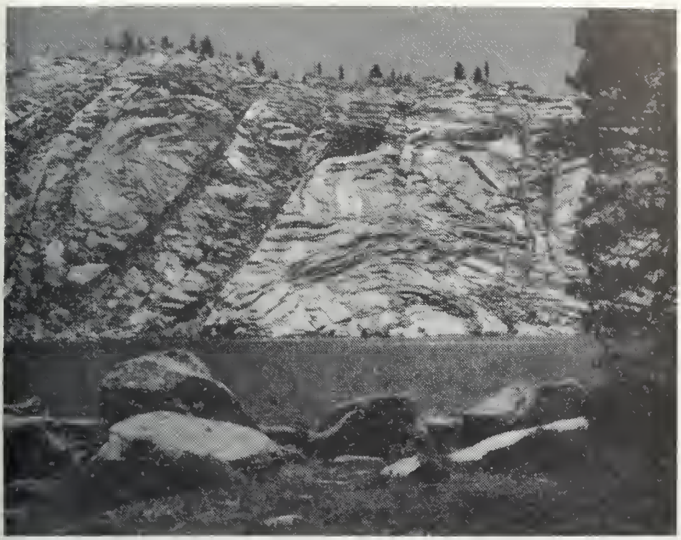


FIGURE 15. Cliff Lake, near Dinkey Lake. North-northeast joints are well developed in granite. Lake is dammed by a small moraine (foreground).

some structural geologists to be the dominant means of emplacement of granitic plutons. However, most geologists (e.g., Durrell 1940, Macdonald 1941, Mayo 1941) who have studied contact relations in the Sierra have concluded that, whatever were the means of intrusion, those means must have been passive.

Forceful injection of plutons should be recorded in features such as marginal brecciation, thrusting, and strong peripheral schistosity of both granitic and metamorphic rocks. Contacts between plutons, as well as between plutons and metamorphic rocks, should show such features; the almost complete lack of them in the Sierra makes forceful injection improbable as the major mode of emplacement.

Although flow structures show that the plutons moved relatively upward past their walls, few contacts indicate that the plutons were sheared along them. On the contrary, crystals generally interlock across contacts, and mineral grains, unbroken on either side, have weak if any orientations. Nearly all contacts have the appearance of static crystallization. Contacts are mostly complexly discordant in detail; if the wall rocks were shouldered aside, they must have been so with shearing distributed through broad zones about the intrusions, not with shearing along the contacts.

At only a few places in the Huntington Lake area was evidence recognized which would favor forcible intrusion of plutons. Along a few hundred yards of the contact between the Rodeo Meadow and Mt. Givens plutons, flow structures in the latter are sharply truncated by the former. A screen of banded dark hornblende-plagioclase rock, possibly a recrystallized mylonite, separates the plutons. However, most of the contact between these two plutons is sharp or swirled to a marble cake appearance in a zone a few tens of yards wide. The swirled part of the contact indicates that the Mt. Givens pluton was not completely solid when it was intruded by the Rodeo Meadow pluton.

The dike-like Helms Creek pluton has a shape and internal structure suggestive of injection.

Some of the pyroxene hornfels in the septum at Idaho Lake is intricately contorted by folding, shearing and flowage. This deformation seems best explained as the result of the force of intrusion of the Mt. Givens pluton when the temperature of the hornfels was raised by contact metamorphism. Even in this area, however, the replacement nature of the contact and the random orientation of minerals in the granodiorite show that the final stage of emplacement was passive.

Permissive Intrusion, Tectonically Controlled. Mayo (1941) suggested that the dominant means of emplacement of Sierra plutons was "permissive intrusion, tectonically controlled." From a reconnaissance structural study of a large area, he concluded (p. 1081) that "the structural features of the region seem in harmony with the idea that space for the intrusion was provided . . . mostly by buckling of the isoclinally folded wall rocks, as a result of north-south compression." Much of the evidence for this process is negative, consisting of demonstrations of the inadequacy of any other processes yet suggested to account for the emplacement of the plutons. Nevertheless, the writer feels that, with modifications of the theory, permissive intrusion may have been an important process in the emplacement of the plutons. The theory does not, however, account for intrusions into older and already solid plutons.

The writer pictures the plutons of the Sierra Nevada to have been emplaced by complex combinations of physical and chemical processes, with the relative importances of the processes varying much in different plutons and with different stages in the same pluton. The plutons formed from mobile magmas which moved upwards and expanded outward, mostly passively but in part forcibly. Large amounts of material were incorporated into the magmas by assimilation of margins and stoped blocks, but most of the granitic material was introduced from lower levels.

VOLCANIC ROCKS

In the Huntington Lake area, volcanic rocks of probable Tertiary age form four peaks: Black Point, Chinese Peak, Red Mountain, and Black Peak. Black Point and Red Mountain are formed of intrusive masses of trachybasalt, and Chinese Peak is capped by remnants of trachybasalt flows. Black Peak is a plug of hornblende andesite.

Trachybasalt. The trachybasalts are red-gray or blue-gray and have small phenocrysts of diopside and red-stained olivine in an aphanitic groundmass. Most contain large amounts of sanidine, poikilitically enclosing the other minerals.

The five thin sections examined of specimens from Black Point are all of trachybasalt, each with about 25 percent sanidine. The sanidine forms a mosaic of small (0.1 mm) to large (several mm) xenomorphic poikilitic grains, in which "float" normal olivine basalt minerals. Olivine and diopside occur as small phenocrysts, and minute crystals of plagioclase (about An_{50}), diopside, magnetite and apatite are enclosed in the sanidine. Miaroles of sanidine and diopside are common.

The three specimens studied from Chinese Peak are similar, except that plagioclase gives the groundmass a felted appearance.

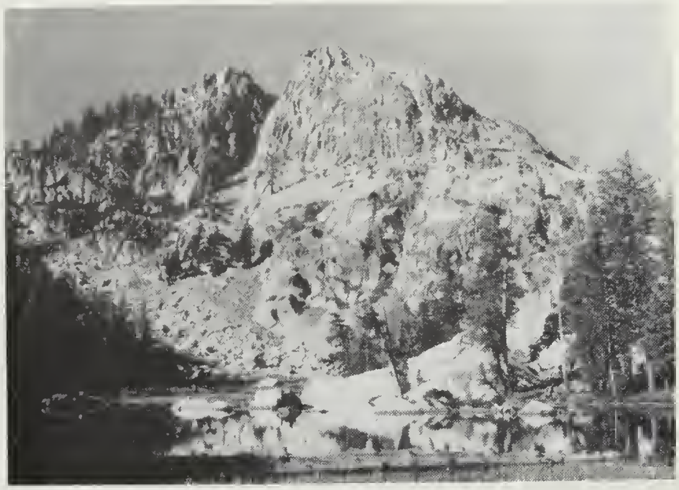


FIGURE 16. Cirque above Twin Lakes. Peak is of quartz monzonite, Kaiser Peak pluton.

Two of the five specimens from Red Mountain are of trachybasalt, similar to that of Chinese Peak. The other three specimens contain no visible sanidine. Phenocrysts of diopside and olivine are set in a felted groundmass of plagioclase microlites and glass. Chemical analysis of one such specimen indicates that the glass must be largely of sanidine composition.

Andesite. The plug of hornblende andesite of Black Peak is roughly elliptical in plan with dimensions of about 1,000 by 1,500 feet and with an exposed vertical extent of about 700 feet. Its contact with the surrounding granitic rocks is steep. The andesite is mostly bluish-gray with conspicuous phenocrysts of euhedral oxyhornblende. Small phenocrysts of augite, often clustered, are common, and flakes of biotite are present though uncommon. The groundmass is a felted mass of intermediate plagioclase laths, magnetite and glass.

GLACIAL GEOLOGY

Much of the Huntington Lake area was covered by ice at several different times during the Quaternary.

A large ice field was present in the broad area of relatively low relief at the headwaters of Big, Tamarack, Dinkey, and Helms Creeks; only the higher peaks were above this ice. The ice flowed out via Big Creek valley to about the center of the present Huntington Lake, via Tamarack Creek valley to about the 7,000 foot level, and via Dinkey and Helms valleys out of the area to the south. This glaciation formed cirques, notably against the north slope of the high crest south of the Dinkey Lakes, left fresh bedrock exposed over large areas, and covered other broad areas with glacial debris.

Several streams tributary from the north to Big Creek below the junction of its South and East Forks deposited small platforms of stream cobbles into a temporary glacial lake. Other glacial features of special interest are several kames, superficially dunelike, of washed sand and gravel in Shorthair Meadow.

The valley of the South Fork of the San Joaquin River was occupied by a large trunk glacier during each of the several glacial stages. A well-developed lateral moraine was left by the most recent ice advance. A previous glacier filled the valley to a higher level and probably over-rode the divide between the South Fork and Kaiser Creek.

The South Fork glacier received a minor contribution from the coalesced cirque glaciers of the north side of the crest east of Kaiser Pass. West of the pass, large cirque and valley glaciers formed and coalesced in the drainage area of Kaiser Creek. Small cirque and valley glaciers formed at many other places along both sides of the crest.

The deposits of the younger glaciation have retained much of their original topographic form. Moraines of varying size and regularity are superimposed on broad areas of ground moraine. Rocks of the debris are relatively fresh. Bedrock in the upper parts of the glacial fields preserves much glacially polished surface, with only a fraction of an inch of rock weathered away where the polish has been removed.

The rocks of the debris of the older glaciation, by contrast, are deeply weathered. Topographic forms of moraines have been lost or made obscure. Of what must have been once extensive ground moraine, only discontinuous patches of deeply weathered erratics remain. Several stages of glaciation might be represented by this debris.

The glacial moraine shown on the geologic map is mostly that of the younger glaciation.

ECONOMIC GEOLOGY

The placer gold deposits (Kaiser Diggings) of Kaiser Creek northwest of the mapped area suggest the possibility that there may be lode-gold deposits in Kaiser Peak area.

Some of the granitic rocks are suitable for use as monument and building stone. For example, the rock of the fine-grained Red Lake pluton is similar to the much quarried granite of the Elberton region of Georgia. However, the remoteness and short working season of the Huntington Lake area would probably prohibit development of quarries under present economic conditions.

Several tungsten deposits are present in the contact-altered marble pendants near Twin Lakes (Chesterman, 1942).

*Lucky Blue Tungsten Mines.** Eight lode and three placer claims are located in sections 13 and 24, T. 7 S., R. 25 E., and sections 18, 19, and 30, T. 7 S., R. 26 E., MDM., in the Kaiser Ridge district. Floyd T. Wilmoth, Auburn, California, holds the property by location.

The property is accessible by a well graded dirt U. S. Forest Service access road from Sample Meadow, a distance of about 3.5 miles from Sample Meadow.

The claims are in several lenticular bodies of metamorphic rocks, the largest of which measures at least 300 feet in length and has a maximum width of 50 feet. This body of metamorphic rock, which has the same strike and dip as the parent sedimentary rocks themselves (N. 37° W.; near vertical), contains zones of calc-silicate hornfels and dark biotite-quartz schist. The hornfels is a fine- to medium-grained rock made up of brown garnet, pale green diopside, epidote, hedenbergite, plagioclase, calcite, and minor amounts of sulfides and scheelite. Local areas contain chlorite, hornblende, and muscovite in addition to the above minerals. The biotite-quartz schist is of a fine-grained rock made up principally of biotite and quartz.

---

* Data on the Lucky Blue tungsten mines was supplied by C. W. Chesterman, Associate Mining Geologist, California Division of Mines.

The metamorphic rocks are surrounded by a medium- to coarse-grained biotite-quartz diorite. Much of the area at Lucky Blue #5 is covered by glacial debris.

Tungsten mineralization can be found on all claims, according to the owner. In the Lucky Blue #5, scheelite appears to be localized in the limey portions of the calc-silicate hornfels and occurs as angular and well shaped crystals ranging in size from mere specks to crystals $\frac{1}{4}$-inch in diameter. The crystals fluoresce pale yellowish-white under the ultraviolet lamp. The calc-silicate hornfels zone is lenticular in shape and can be traced discontinuously along its strike for about 100 feet. At the open cut it has an exposed width of 10 feet.

Mr. Wilmoth stated that the ore assays from 0.01 to 9 percent WO_3. He has produced approximately 200 tons of ore averaging 0.85 percent WO_3. He plans to sink a developmental and exploratory shaft in the summer of 1955, and also to install a 50-ton mill to handle the ore mined from the shaft.

REFERENCES

Beal, Carl H., 1948, Reconnaissance of the geology and oil possibilities of Baja California: Geol. Soc. America Mem. 31, 138 pp.

Bowen, N. L., 1928, The evolution of the igneous rocks: Princeton University Press.

Calkins, F. C., 1930, The granitic rocks of the Yosemite region: U. S. Geol. Survey Prof. Paper 160, pp. 120-129.

Chesterman, Charles W., 1942, Contact metamorphic rocks of the Twin Lakes region, Fresno County, California: California Jour. Mines and Geology, vol. 38, pp. 243-281.

Durrell, Cordell, 1940, Metamorphism in the southern Sierra Nevada northeast of Visalia, California: Univ. Calif., Dept. Geol. Sci., Bull., vol. 25, no. 1, pp. 1-118.

Geological Survey of Canada, 1947, Geology and economic minerals of Canada (3rd ed.); Geol. Survey Canada, Econ. Geology Series no. 1, 357 pp.

Goodspeed, G. E., 1940, Pre-Tertiary metasomatic processes in the southeastern portion of the Wallowa Mountains of Oregon: Sixth Pacific Science Congress Proc., vol. 1, pp. 399-422.

Goodspeed, G. E., 1948, Origin of granites: pp. 55-78 *in* James Gillnly, Chairman, Origin of granite: Geol. Soc. America Mem. 28.

Grout, Frank F., 1937, Criteria of origin of inclusions in plutonic rocks: Geol. Soc. America Bull., vol. 48, pp. 1521-1572.

Hinds, N. E. A., 1934, The Jurassic age of the last granitoid intrusives in the Klamath Mountains and Sierra Nevada, California: Am. Jour. Sci., 5th Ser., vol. 27, pp. 182-192.

Knopf, Adolph, 1918, A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, 130 pp.

Krauskopf, K. B., 1953, Tungsten deposits of Madera, Fresno and Tulare Counties, California: California Div. Mines Special Rept. 35, 83 pp.

Larsen, E. S., Jr., Gottfried, David, Joffe, H., and Waring, C. L., 1954, Age of the southern California, Sierra Nevada and Idaho batholiths (abstract): Geol. Soc. America Bull., vol. 65, p. 1277.

Macdonald, Gordon A., 1941, Geology of the western Sierra Nevada between the Kings and San Joaquin Rivers, California: Univ. Calif. Dept. Geol. Sci. Bull., vol. 26, no. 2, pp. 215-286.

Mayo, Evans B., 1941, Deformation in the interval Mt. Lyell-Mt. Whitney, California: Geol. Soc. America Bull., vol. 52, pp. 1001-1084.

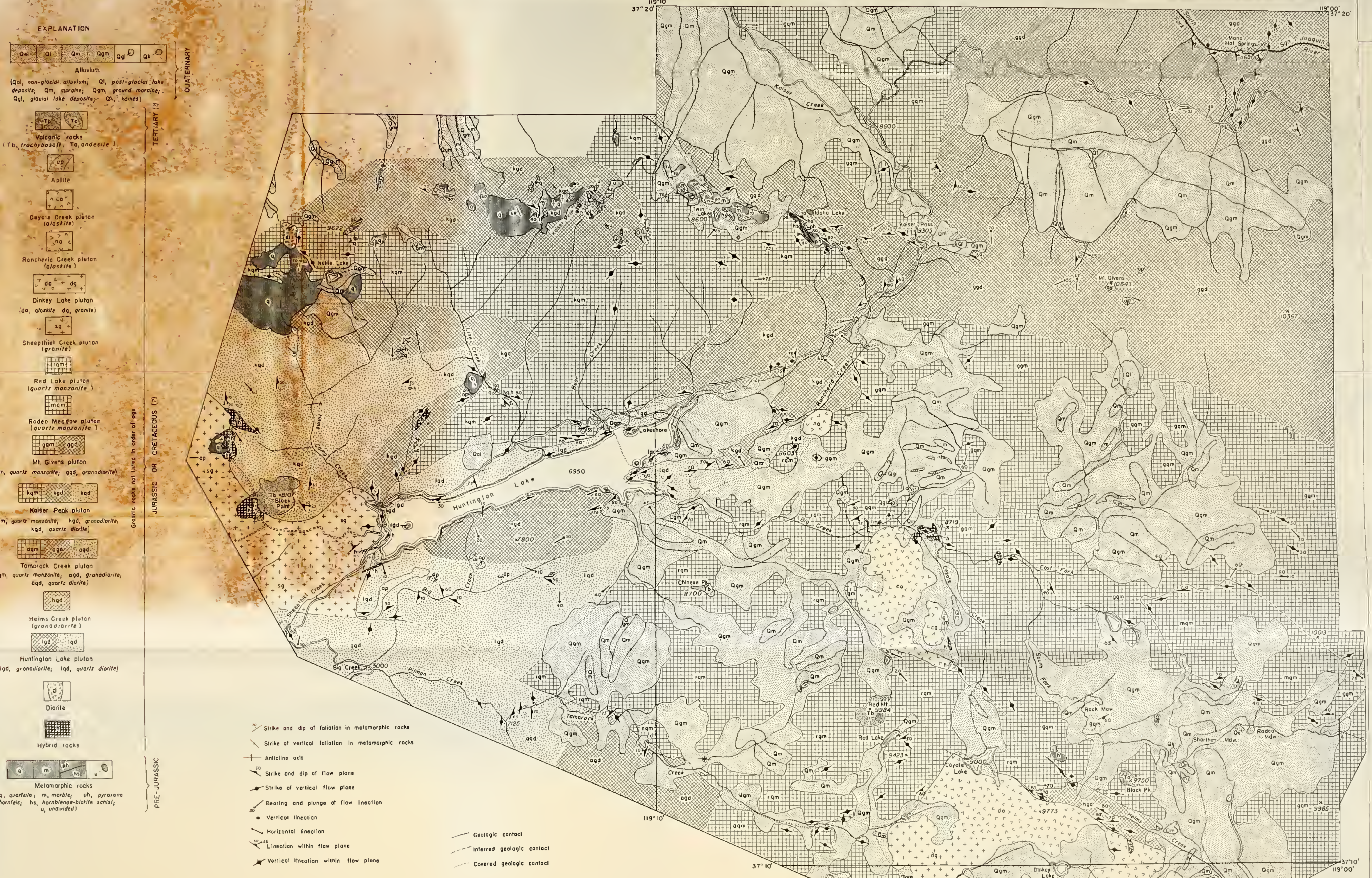
Pabst, Adolf, 1928, Observations on inclusions in the granitic rocks of the Sierra Nevada: Univ. Calif. Dept. Geol. Sci., Bull., vol. 17, no. 10, pp. 325-386.

United States Department of Agriculture, 1941, Climate and Man: Yearbook of Agriculture.

Woodford, A. O., 1940, Pre-Tertiary diastrophism and plutonism in southern California and Lower California: Sixth Pacific Sci. Congress, Proc., vol. 1, pp. 253-258.

33805 4-56 2500

printed in CALIFORNIA STATE PRINTING OFFICE



GEOLOGIC MAP OF THE HUNTINGTON LAKE AREA

FRESNO COUNTY, CALIFORNIA

SCALE
1 0 1 2 3 4 5 Miles

Elevations (U. S. G. S.) are in feet above sea level

Base map compiled from aerial photographs
by Warren B. Hamilton

Geology by Warren B. Hamilton
Surveyed 1948–1950